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A STUDY OF THE POLLUTION AND NATURAL
PURIFICATION OF THE SCIOTO RIVER

Robert W. Kehr, et al

Public Health Service
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No. 276

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Public Health Bulletin No. 276

**A STUDY OF THE POLLUTION
AND NATURAL PURIFICATION
OF THE SCIOTO RIVER**

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ABSTRACT

Hydrometric, bacteriological, chemical, plankton, and bottom sediment studies were made of the Scioto River for 115 river miles below Columbus, Ohio, during a period of 30 months, involving three types of sewage treatment at Columbus, the point of heaviest pollution of the Scioto. These periods were: first, 10 months' treatment, overloaded trickling filter; second, 8 months' treatment, plain sedimentation; and third, 12 months' treatment, activated sludge.

Times of flow were determined for the stretch of river between Shadeville and Red Bridge 8 and 25 miles, respectively, below the point of entrance of Columbus sewage effluent. Cross sections of the river channel, with soundings at low water, were made and the mean velocity determined from the discharge and mean river cross sectional area.

The bacteriological and chemical data were grouped according to three temperature and five discharge ranges and in addition, for the upper half of the river, the three periods of varying pollution at Columbus. Rates of decrease of bacteria in the river were linear when plotted on semilog paper in the Shadeville-Red Bridge stretch and, roughly so, at low stages downstream. At progressively higher discharges, rates of bacterial decrease were less in the relatively less polluted, lower half of the stream. Rates of bacterial decrease were greater at higher temperatures and were in the approximate range of previously observed rates on the Ohio and Illinois rivers.

Rates of biochemical oxygen demand decrease in the Shadeville to Red Bridge stretch were greater at low than at high temperatures and a number of factors which may have contributed to this unusual result are discussed. Dissolved oxygen profiles at the different temperature and flow ranges, and periods of varying pollution, form a nicely graduated set of oxygen sag curves. An extensive series of reaeration calculations are presented but the computed values for maximum atmospheric reaeration rates were quite variable.

Both the chemical and bacteriological data indicated that pollution in the Shadeville to Red Bridge stretch during the second period (of sewage treatment at Columbus) was much greater than would be expected considering the relative amounts of biochemical oxygen demand discharged at Columbus during the first and second periods. Pollution in this stretch during the third period was relatively about the same as during the first as indicated roughly by the data available. Neither the plankton nor bottom sediments reflected conclusively the

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changes in amount of pollution at Columbus resulting from changes in type of sewage treatment.

The Scioto proved to be highly productive of plankton algae and protozoa, exceeding both in the variety of species and in total plankton volume that of previously reported streams. The use of entire groups of organisms as indicators of pollution was found to be fallacious but certain individual species were sufficiently selective of environment to enable their use as indicators of the presence or absence of pollution.

Bottom sediments form a stable record of the average quality of water in the stream during the period of their formation. A careful examination of the physical properties and biological content of such sediments gives a reasonably accurate picture of average stream conditions. The composite picture obtained from such an examination must be used, however, inasmuch as certain factors, such as the transportation of egg capsules downstream, will result in the temporary presence of small numbers of foul water organisms in a clean water environment.

A STUDY OF THE POLLUTION AND NATURAL PURIFICATION OF THE SCIOTO RIVER

INTRODUCTION

This survey of the Scioto River is the fifth of a series of extensive investigations made by the Stream Pollution Investigations Station of the processes of natural purification in polluted waters, previous surveys having been made of the Ohio, Illinois, and upper Mississippi Rivers and of southern Lake Michigan. The survey was undertaken to obtain definite measurements of the transformations occurring in a stream following major changes in the intensity of pollution and to obtain data on the rates of natural purification in a smaller stream.

The section of the Scioto studied was 115 stream miles beginning at Columbus, Ohio, at the junction of the Scioto and Olentangy Rivers and extending down to Lucasville, Ohio, 16 miles above the point where the Scioto empties into the Ohio River. This is roughly the lower two-thirds of the Scioto River.

As originally planned, the river was to be observed for a year prior to and a year following the change in sewage treatment from an overloaded trickling filter to activated sludge at Columbus, Ohio, the point of heaviest pollution received by the Scioto. The survey was started in February 1937, and 10 months' observations were obtained before the first change in sewage treatment at Columbus. During the following 8 months Columbus sewage was treated in a newly constructed plant by plain sedimentation only, resulting in a more intense pollution than during the first period. A year's observations ending in July 1939, were obtained after activated sludge treatment was started at Columbus but on numerous occasions during this year difficulties with the sludge concentrating mechanism at the Columbus plant necessitated the discharge of sludge into the river. If possible, it is planned later to study the river below Columbus during a period when the Columbus plant is operating efficiently.

In analyzing the large mass of data accumulated during the 30 months of the survey, the results have, in general, been summarized according to stream discharge and temperature ranges rather than by monthly averages.

The biological examinations made during this survey are somewhat more extensive than in the previous surveys made at this station, a complete set of samples usually being examined weekly.

The United States Geological Survey District offices at Columbus, Ohio, under District Engineer C. V. Youngquist, furnished the discharge measurements used in the hydrometric studies.

The survey is also greatly indebted to the city of Chillicothe and to Mr. C. S. Houser, Superintendent of the Chillicothe Sewage Treatment Plant, for their generous cooperation in furnishing laboratory space and facilities.

DESCRIPTION OF THE RIVER AND ITS WATERSHED

WATERSHED

The Scioto River, a tributary of the Ohio River, drains an area of 6,510 square miles, roughly rectangular in shape, located in the south central part of the State of Ohio. As seen in figure 1, the watershed extends in a narrow band about 50 miles wide for a distance of 130 miles north from the Ohio River. It is bounded principally by the Miami and Little Miami watersheds on the west, the Muskingum and Hocking watersheds on the east, all of which are tributary to the Ohio River, and on the north by the Sandusky watershed which drains into Lake Erie.

The area north of Chillicothe is glaciated and generally level to gently rolling in character forming an extensive agricultural region. The southern part of the basin is unglaciated and rugged in character with steep slopes of shale and soft sandstone which give rapid rates of run-off.

In the extreme northern part of the watershed above Prospect the slope of the rock underlying the glacial drift is toward the north so that an indeterminate portion of the ground water in this region drains northward toward Lake Erie.

The valley proper averages about 12 miles in width below Columbus and forms a very fertile and rich agricultural region. It is subject to floods and is protected in many places by systems of levees which have not in general been maintained since the extensive damage suffered during the 1913 flood. Remains of the old Ohio and Lake Erie Canal are visible throughout the length of the valley, but they do not affect the river except to form minor channels during floods. The river below Chillicothe lies in a preglacial valley which has been filled with glacial outwash to a depth of 100-250 feet, forming an extensive reservoir for underground water.

CHARACTER OF THE RIVER

In common with most streams of its size or smaller, the Scioto is characterized by flashy rises, but flood levels are generally minimized by the long narrow shape of the watershed.

The profile of the Scioto is rather erratic in that it has a fairly low slope in its upper reaches, averaging slightly under 2 feet per mile for the first 60 miles. For the next 40 miles, the stretch immediately above Columbus, the river flows through a limestone gorge with a

FIGURE 1. MAP OF SCIOTO WATERSHED SHOWING PRINCIPAL TRIBUTARIES AND SAMPLING POINTS. THE LATTER ARE NUMBERED ACCORDING TO MILEAGE BELOW JUNCTION OF SCIOTO AND OLENTANGY RIVERS.

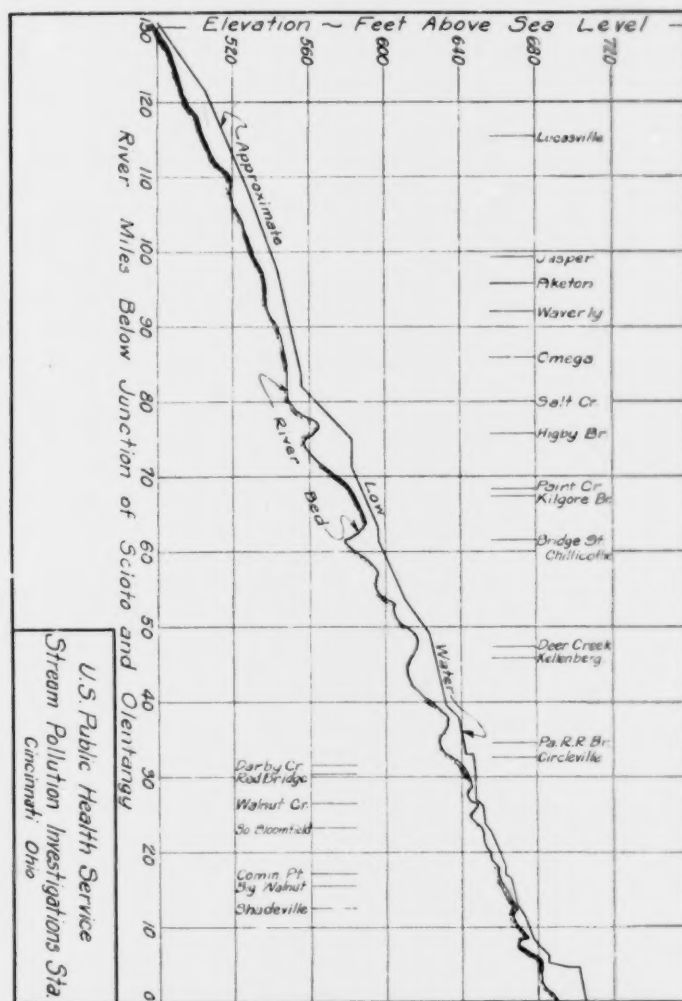


FIGURE 2. PROFILE OF SCIOTO RIVER FROM COLUMBUS SOUTH TO THE MOUTH. DATA DOWNSTREAM FROM CIRCLEVILLE OBTAINED FROM ALVORD AND BURDICK'S REPORT OF FLOOD RELIEF TO THE FRANKLIN COUNTY CONSERVANCY DISTRICT.

drop of about 5 feet per mile. Below Columbus, as can be seen in figure 2, the slope is rather uniform and averages about 1.6 feet per mile. From Columbus to Chillicothe, the Scioto at low water forms a series of pools and riffles (figures 3 and 4) usually with gravel bottoms except in a few of the larger pools where occasionally a mud bottom is encountered. Below Chillicothe there is a general tendency for the river bottom and alluvial deposits to become more sandy in character. In addition, there are, during the period of this survey, sewage sludge deposits immediately below the points of heaviest pollution.

Figure 5 is a mean cross section of the river between Columbus and Red Bridge, sampling point (30). The average width of the Scioto at low water is 178 feet, the average cross sectional area 513 square feet, thus giving a mean depth of 2.9 feet. Banks along the main channel of the river as observed during a survey of this section average from 6-12 feet in height and are in general covered with a growth of underbrush and trees. Low water in the channel as illustrated in figure 5 corresponds to a discharge of 90 c. f. s. below Columbus, of which 60 c. f. s. is Columbus sewage effluent or a dilution of $\frac{1}{2}$:1 for Columbus effluent. A 7-foot rise in the river, approximately filling the channel as shown, would correspond roughly to discharges of about 7,000 c. f. s. below Columbus, giving a dilution of over 100:1 for Columbus effluent.

River flows are altered below Columbus by Griggs and O'Shaughnessy Dams, built by the City of Columbus to provide storage for water supply purposes. These dams are located 10 and 17 miles above the city and impound 1.5 and 5.4 billion gallons respectively. Sufficient water is released into the river from these reservoirs to maintain an adequate water supply in the waterworks intake pool created by a low water dam located in the city of Columbus. Return of this water to the stream in the form of sewage effluent provides a minimum flow in the river of about 60 c. f. s. with very little dilution during prolonged dry periods, the only dilution being flow from the Olentangy River. This condition is general during the late summer and fall and extends over longer periods during prolonged drought. The reservoirs also tend to reduce river discharges at downstream points during the periods when they are filling.

TRIBUTARIES

In the vicinity of Columbus the Scioto receives the discharge from two tributaries, the Olentangy and Big Walnut, which approximately double its watershed area of 1,076 square miles above Columbus. Both of these tributaries enter from the east and both drain areas north of Columbus. Between Columbus and Chillicothe, excepting Big Walnut



FIGURE 3.—Scioto River upstream from Circleville. Picture taken from the Circleville (23) sampling point at low water (estimated discharge 384 c. f. s.).

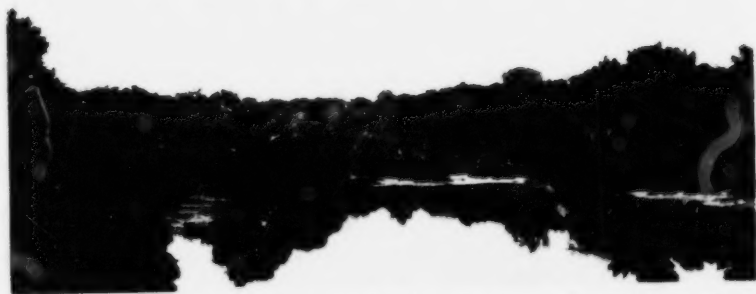


FIGURE 4.—Scioto River south of South Bloomfield Bridge. This photograph, taken at low water (estimated discharge 223 c. f. s.) shows one of the frequent islands covered with underbrush.

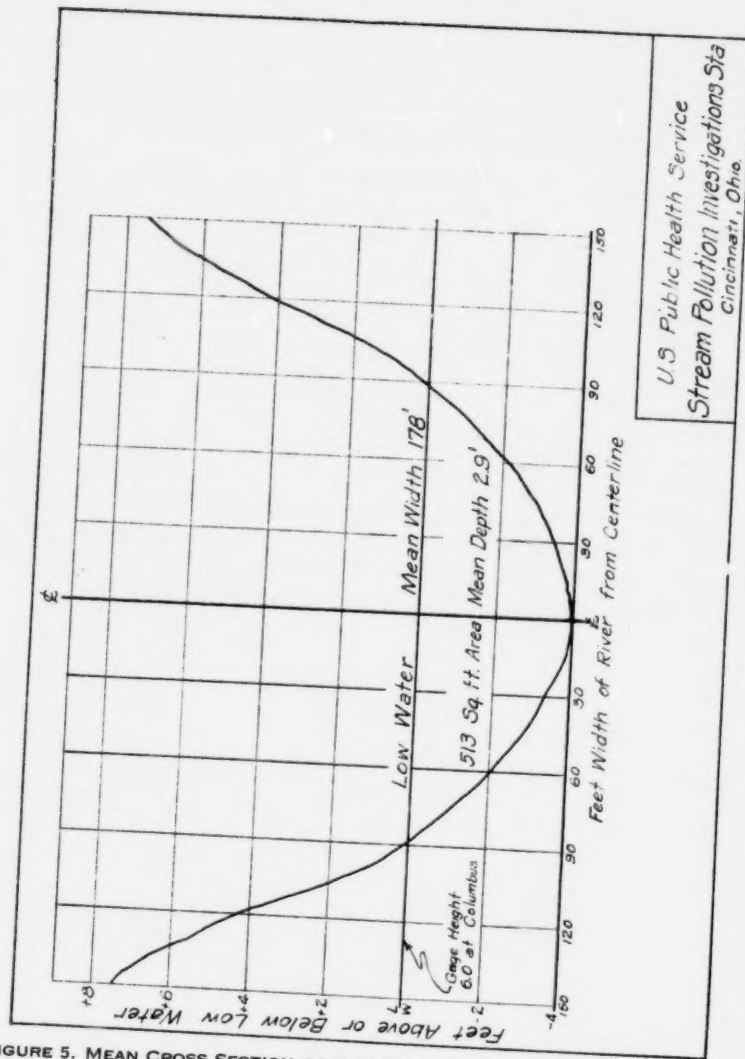


FIGURE 5. MEAN CROSS SECTION OF THE RIVER CHANNEL BETWEEN COLUMBUS AND RED BRIDGE.

and Walnut Creeks, the latter having a drainage area of 281 square miles, no major tributaries enter from the east as the Scioto swings to the eastern side of its watershed. Two major tributaries, Darby Creek and Deer Creek, enter from the west, however, and the largest tributary, Paint Creek, with a drainage area of 1,143 square miles, enters just below Chillicothe. Salt Creek, which enters the Scioto from the east 16 miles below Chillicothe, is the only other tributary of note. A list of tributaries of the Scioto is given in table I.

Table I.—Principal tributaries of the Scioto River

Tributary	Mile ¹	Drainage area	Percent of total Scioto watershed	Enters Scioto from—
Scioto above Oolintangy		1,076	16.5	
Oolintangy	0	536	8.2	East.
Big Walnut Creek	15	557	8.6	East.
Walnut Creek	26	281	4.3	East.
Darby Creek	32	557	8.6	West.
Deer Creek	47	408	6.3	West.
Paint Creek	68	1,143	17.6	West.
Salt Creek	80	553	8.5	East.
Sunfish Creek	103	145	2.2	West.
Scioto Brush Creek	120	273	4.2	West.

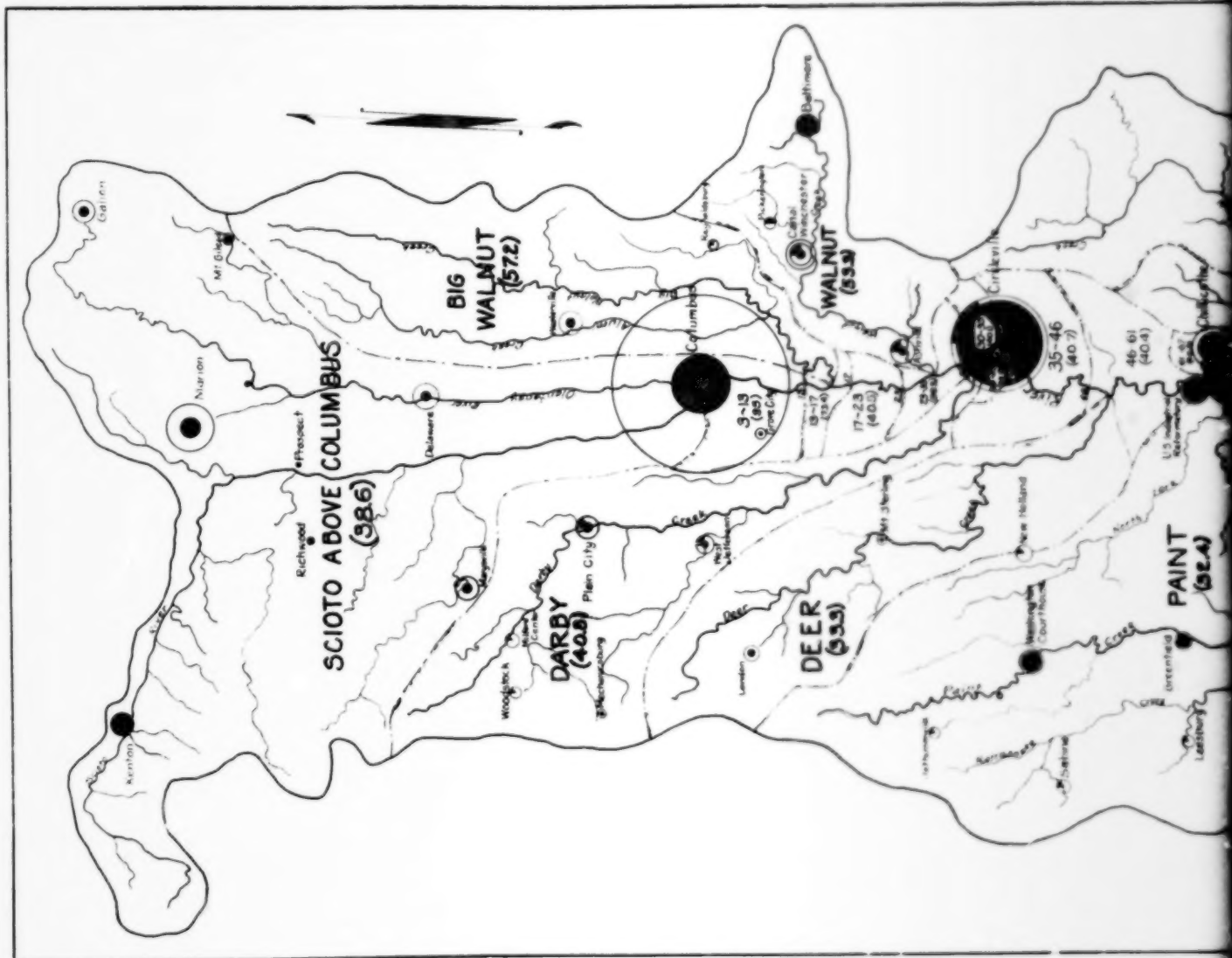
¹ River miles below junction of Scioto and Oolintangy.

Figure 6 is a photograph of Darby Creek showing the general nature of the tributaries, rapidly flowing clear streams with gravel bottoms. Excepting Paint Creek, all tributaries below Columbus are relatively unpolluted at their point of discharge into the Scioto.



FIGURE 6. Darby Creek. Photograph of Darby Creek upstream from its sampling point, a covered wooden bridge on Ohio Route No. 101.

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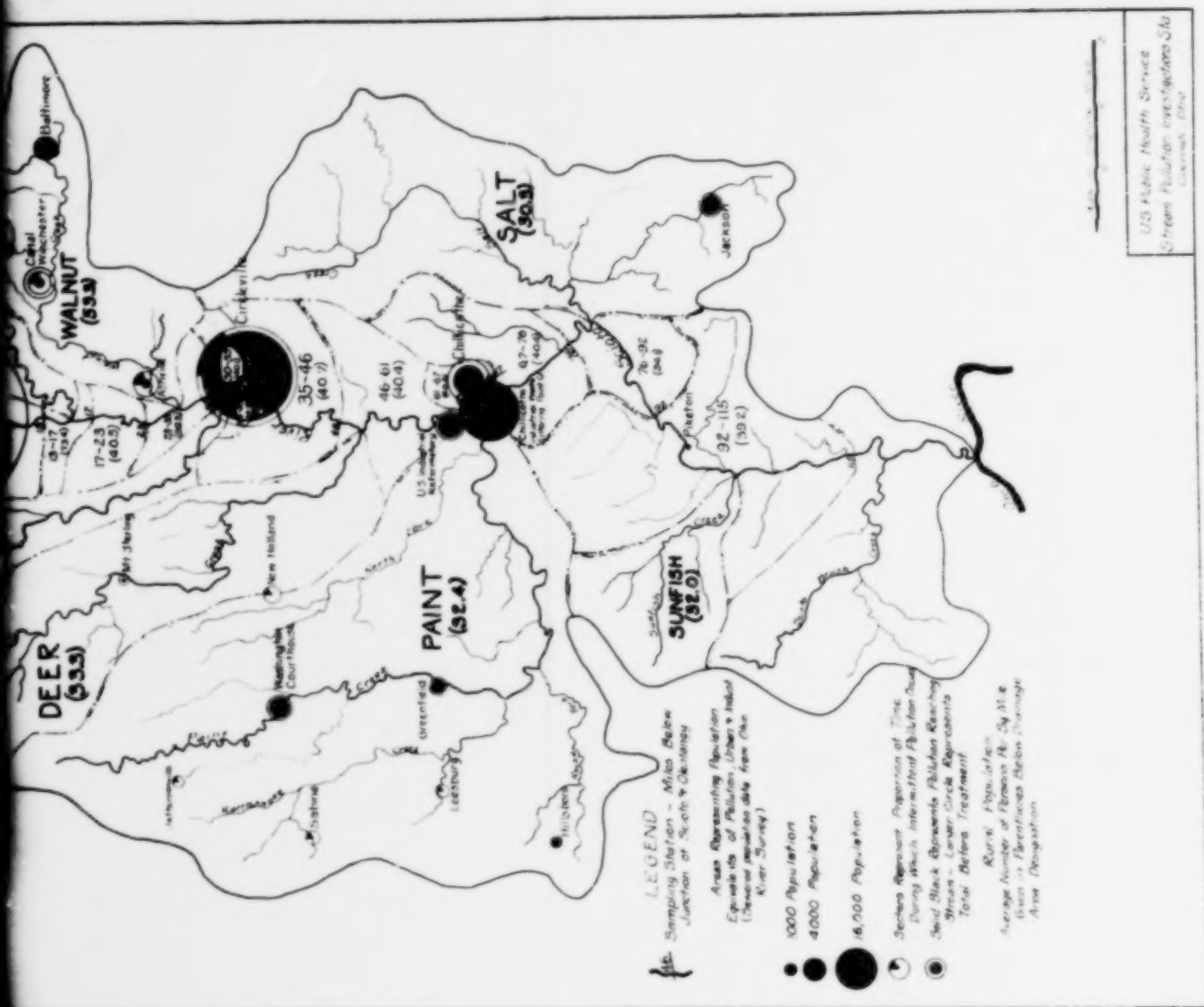


FIGURE 7. RURAL AND URBAN POLLUTION ON THE SCIOTO WATERSHED

DISTRIBUTION OF POPULATION AND SOURCES OF POLLUTION

RURAL POPULATION

In studying the distribution of population on the Scioto watershed, the population as of April 1, 1938, approximately the midpoint of the survey, was computed by applying an arithmetic rate of increase or decrease to the 1930 census based on the changes occurring between the 1920 and 1930 censuses. Populations were divided into urban or rural depending on the existence of a central sewer system. In allocating the rural population of a county which lies in more than one drainage basin, a uniform distribution of population was assumed to exist and the percentage of the area, or population, within the watershed was determined by planimeter. The average rural populations, expressed as persons per square mile, are given in figure 7 for the major tributaries and for the remaining sections of the watershed tributary to the river between sampling points. These average populations per square mile are shown in parentheses immediately below the designation of each tributary, or below numbers indicating the areas directly tributary to the river between the sampling points represented by those numbers. Sampling point numbers represent river mileage below the junction of the Scioto and Olentangy Rivers. The rural areas most densely populated lie immediately below Columbus with a small area tributary to Shadeville sampling station (13) having 95 persons per square mile and another, tributary to Commercial Point sampling station (17), having 73.4 persons per square mile. Big Walnut and Walnut Creek basins have 57.2 and 53.3 persons respectively per square mile. The remainder of the Scioto watershed varies from 30.3 per square mile for the Salt Creek Basin to 40.8 on Darby Creek Basin, with the areas directly tributary to the river all having about 40 persons per square mile.

URBAN POPULATION AND INDUSTRIAL WASTES

The concentrated sources of pollution on the Scioto watershed, sewage and industrial wastes, are also shown on figure 7. These sources are indicated by circles, the area of the circle being proportional to the estimated pollution load, in population equivalents of biochemical oxygen demand (B. O. D.), at that point. In deriving the population equivalents for sewage and industrial wastes, most of the data were obtained from the joint survey of the Ohio River Basin

being made at present by the U. S. Public Health Service and U. S. Army Corps of Engineers, and the constant used in these figures was 0.167 lbs. of 5-day B. O. D. per person per day. Sewered populations, or the estimated population equivalents of the raw sewage or industrial wastes are shown by the larger circles in figure 7 and the population equivalents of wastes polluting the stream are shown in black, sectors of circles indicating the percentage of time which intermittent or seasonal wastes, usually from canneries, are discharged to the stream. No distinction was made between domestic sewage and industrial wastes in computing the pollutional loads on the Scioto and its tributaries.

Both the rural population and the population equivalents of polluting substances are given in table II, which summarizes the data shown

Table II.—Equivalent populations tributary to the stream between sampling points

Sampling point and its mileage below junction of Scioto and Olentangy	Tributary designation	Rural population		Population equivalents urban sewage	Population equivalents industrial wastes
		Total	Per square mile		
(3) Greenlawn Ave. Columbus.	Scioto River, Above Mile 3.....	62,500	39	12,200	1,000
(13) Shadeville.....	Scioto River, Miles 3-13.....	7,200	95	1(37,000)	
(17) Commercial Pt.	Scioto River, Miles 13-17.....	1,400	73		
(23) South Bloomfield.	Big Walnut Creek.....	31,900	57	540	875
	Scioto River, Miles 17-23.....	1,600	40		
	Scioto River, Miles 23-30.....	1,690	39		
(30) Red Bridge.....	Walnut Creek.....	15,000	53	1,140	16,100
(33) Circleville.....	Scioto River, Miles 30-33.....	923	40		
(35) Pennsylvania R. R. bridge.	Darby Creek.....	22,700	41	1,330	12,500
(46) Kellenberger Bridge.	Scioto River, Miles 33-35.....	161	40	4,600	100,000
	Scioto River, Miles 35-46.....	5,300	41		
(61) Bridge St. Chillicothe.	Scioto River, Miles 46-61.....	3,600	40	5,300	
(67) Kilgore Bridge.....	Deer Creek.....	13,600	33	270	200
(76) Highby.....	Scioto River, Miles 61-67.....	600	40	8,900	
(92) Waverly.....	Scioto River, Miles 67-76.....	5,000	40		
(115) Lucasville.....	Paint Creek.....	37,000	32	6,810	42,100
	Scioto River, Miles 76-92.....	2,280	34		
	Salt Creek.....	16,450	30	2,600	4,400
	Scioto River, Miles 92-115.....	11,000	39		
	Sunfish Creek.....	4,630	32		

¹ Based on complete treatment (90% removal at Columbus).

on figure 7 into areas tributary to the various river sampling points, the major tributary basins, however, being carried separately from that directly tributary to the Scioto, itself. In computing the amounts removed by treatment, where actual figures were not available, plain sedimentation was assumed to remove 40 percent of the 5-day B. O. D., complete treatment with trickling filters 85 percent, and complete treatment with activated sludge or sand filters 90 percent of the 5-day B. O. D. Pollution at Columbus, in both figure 7 and table II, was based on complete treatment with activated sludge, although the



FIGURE 8. Scioto River downstream from Circleville sampling point 333. Pollution from cannery wastes is visible as a light-colored patch between the two piers on the right. The smokestack and water tower are at the strawboard plant, also a heavy contributor of pollution. At the extreme right of the picture is located the new sewage and industrial waste-treatment plant of Circleville, under construction at the time of this photograph.

actual amount of pollution discharged at this point varied widely during the survey.

The three major sources of pollution on the Scioto are the Columbus, Circleville, and Chillicothe areas. Chemical treatment has been provided in the Circleville area for both sewage and industrial wastes, but treatment of the industrial wastes, which constitute by far the major portion of the pollution load at that point, had not been started by July 1939.

Figure 8 shows the pollution of the Scioto from Circleville wastes. This picture was taken downstream from sampling point 33 on August 12, 1938. Domestic sewage is treated at Chillicothe, but there is still a heavy industrial waste load discharged, untreated, into Paint Creek.

HYDROMETRIC STUDIES

As in previous surveys on the Ohio (1) (2),¹ Illinois (3), and Mississippi (4) Rivers, the hydrometric studies were made along two lines:

(a) An estimate of the daily discharge at each sampling point and, from these, the average discharge at that point during a month or other period being studied. These are necessary to obtain quantitative estimates with respect to the river as a whole.

(b) Estimates of the times of flow with varying gage heights in that section of river between the Columbus main sewer outlet and Red Bridge, this being the section where the pollution is most intense and where the greater part of natural purification occurs. Estimates of the time of flow are necessary since these previous surveys and other studies have shown natural purification processes to be dependent upon time of flow rather than river distances.

As in the Ohio, Illinois, and Mississippi River studies, sampling points, tributaries, and gaging stations were designated by their distance in miles from a given point, in this case the distance below the junction of the Scioto and Olentangy Rivers in the City of Columbus. Mileages were determined by scaling along the axis of the river channel as shown on the U. S. Geological Survey maps, which had a scale of 1:62,500. Sampling station designations indicate the nearest unit of mileage. In table III are given the mileages of each of the sampling points, the sampling point designations, the locations of the various gaging stations, and the points of confluence and drainage areas of the principal tributaries.

In the determination of the drainage areas, those shown in table III as drainage areas above influent tributaries and the drainage areas of the tributaries were taken from a bulletin by C. E. Sherman (5).

The drainage areas at sampling points and at other points not given in Mr. Sherman's bulletin were obtained by tracing out the drainage divides and planimetrying the residual drainage areas on U. S. Geological Survey topographic maps, which was also the method used by Mr. Sherman. The drainage areas thus obtained were checked by summation downstream.

ESTIMATES OF DAILY DISCHARGES AT SAMPLING POINTS

The U. S. Geological Survey maintains three of the four main river gaging stations. These are the recording gages at Columbus, Chillicothe and Higby. A fourth recording gage, located at Red Bridge,

¹ Numbers in *italics* in parentheses refer to titles in Bibliography on pp. 144-146.

2.3 miles above Circleville, was maintained partly by the U. S. Geological Survey and, for a period, by the U. S. Public Health Service. This latter was also true of the gage on Big Walnut Creek at Rees while gages on Deer Creek, Darby Creek, Paint Creek, and Salt Creek were maintained during the latter part of the survey by the U. S. Geological Survey with funds made available by the U. S. Army, Corps of Engineers, but records are not complete during the period of the survey for the tributary gages.

Table III.—Location of sampling points, gages, and tributaries

Basis of computing daily discharge	Mileage	Point	Sampling station designation	Drainage area above point, square miles	Drainage area of tributary, square miles	Elevation zero of gage
0.9975 a	0	Junction Scioto and Olentangy		1,613		
a	3.0	Greenlawn Avenue Bridge	3	1,620		
	5.1	Columbus Gage		1,624		680.4
	5.1	Sewer outfall, 1st period				
	5.4	New Columbus sewer outfall				
1.044 a	12.5	Shadeville Bridge	13	1,696		
	15.3	Big Walnut Creek		1,708	557	
a+0.291 b	17.1	Commercial Point Bridge	17	2,271		
a+0.309 b	24.1	South Bloomfield Bridge	24	2,311		
	26.4	Walnut Creek		2,323	281	
a+0.455 b	30.3	Red Bridge Gage	30	2,635		644.4
	31.6	Darby Creek		2,636	557	
a+0.716 b	32.6	Circleville Bridge	33	3,215		
	32.8	Circleville Sewer outlet				
a+0.717 b	34.6	Pennsylvania Railroad bridge	35	3,219		
a+0.776 b	45.9	Kellenberger Bridge	46	3,349		
	47.3	Deer Creek		3,351	408	
	61.4	Bridge Street, Chillicothe	61	3,847		
c	61.5	Chillicothe Gage		3,847		594.02
	64.1	Chillicothe Sewer outlet				
1.004 e	67.2	Kilgore Bridge	67	3,862		
	68.1	Paint Creek		3,864	1,113	
d	75.7	Higby Bridge Gage	76	5,129	553	567.635
	80.0	Salt Creek		5,133		
1.121 d	92.0	Waverly Bridge	92	5,719		
		Sunfish Creek		5,943	145	
1.204 d	115.4	Lucasville Bridge	115	6,175		
	130.6	Mouth of Scioto		6,510		

a = Discharge at Columbus gage.

b = Discharge at Chillicothe gage less discharge at Columbus gage.

c = Discharge at Chillicothe gage.

d = Discharge at Higby gage.

The basis for estimates of daily discharge at the various main river sampling points are given in table III. Daily discharges at Columbus (3) and Shadeville (13) sampling points are based on the discharge at Columbus assuming a uniform run-off per square mile drainage area. From Commercial Point (17) downstream to Kellenberger Bridge (46) the increase in discharge between the Columbus and Chillicothe gages was distributed according to the increase in drainage area at the sampling points. The discharge at Kilgore Bridge (67) was based on the Chillicothe gage and that at Waverly (92) and Lucasville (115) on the Higby gage, assuming a uniform run-off per square mile. The Higby gage did not go into operation until March 15, 1937, so for the first 1½ months of the survey the discharges at all stations below Chillicothe were based on the Chillicothe gage.

Table IV gives the monthly average of daily discharges at all sampling points for the days on which samples were collected. These have been divided into three periods according to the method of treatment of Columbus sewage as follows:

Table IV.—Mean discharges, by months, at sampling points for days on which samples were collected

PERIOD I. FEBRUARY 3 TO NOVEMBER 30, 1937													
Month	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.			
Sampling point	Mean Discharge—c. f. s.												
3	1,760	1,040	2,100	676	3,490	1,930	391	144	254	107			
13	1,840	1,090	2,200	707	3,660	2,020	409	151	266	112			
17	2,670	1,440	2,760	1,080	4,130	2,760	549	254	322	183			
23			3,940	1,100	4,180	2,810	559	281	343	187			
30	3,140	1,660	3,120	1,500	4,490	3,220	638	346	376	225			
33	3,670	2,610	3,720	1,910	5,090	3,960	779	414	420	263			
35	3,820	2,010	3,720	1,880	4,010	3,090	779	415	420	263			
46				2,040	5,280	3,440	920	537	382	309			
61	4,850	2,480	4,480	2,160	7,280	4,300	1,320	485	615	368			
67		2,530	4,490	2,170	9,460	3,100	1,320	487	516	369			
76		3,500	5,590	3,130	9,740	4,850	2,070	931	822	510			
92	8,170	3,850	6,270	3,510	10,900	5,430	2,320	1,040	920	571			
115	8,690	4,130	6,730	3,770	11,700	5,840	2,490	1,120	989	614			
PERIOD II. DECEMBER 1, 1937, TO JULY 15, 1938													
Month	Dec.	Jan.	Feb.	Mar.	April	May	June	July					
Sampling point	Mean Discharge—c. f. s.												
3	1,150	588	2,650	4,430	4,300	771	562	951					
13	1,210	615	2,770	4,620	4,590	809	606	994					
17	1,550	927	3,720	3,970	1,320	1,390	969	1,260					
23	1,580	948	4,086	6,320	6,010	1,550	1,020	1,280					
30	1,830	1,120	4,500	9,210	4,510	1,920	1,280	1,440					
33	2,130	1,420	5,750	7,970	4,430	2,570	1,600	1,720					
35	2,050	1,420	5,940	8,810	8,150	2,580	1,600	1,720					
46	2,280	1,590	6,570	10,800	6,560	2,630	1,610	1,780					
61	2,920	1,530	7,380	11,990	4,760	3,830	1,500	1,440					
67	2,920	1,530	7,420	11,990	4,770	3,860	1,730						
76	3,820	2,340	9,320	17,300	6,720	7,600	1,990	2,160					
92	4,280	2,620	10,400	19,400	7,540	8,520	2,760						
115	4,600	2,820	11,200	20,900	8,100	9,140	2,990						
PERIOD III. JULY 16, 1938, TO JULY 24, 1939													
Month	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July
Sampling point	Mean Discharge—c. f. s.												
3	191	660	220	105	145	233	646	3,060	5,000	3,480	392	2,680	931
13	199	691	231	110	152	243	677	3,180	5,330	3,650	410	2,800	974
17	381	1,000	485	190	271	376	845	4,640	6,100	5,480	663	3,370	1,290
23	393	1,020	502	195	278	385	858	4,750	6,160	5,590	680	3,410	1,310
30	488	1,200	634	237	342	457	957	5,530	6,660	6,580	856	3,740	1,490
33	658	1,500	871	313	454	585	1,130	6,960	7,560	8,360	1,060	4,360	1,810
35	659	1,510	872	313	454	586	1,130	6,970	7,560	8,370	1,060	4,360	1,810
46	668	1,360	846	333	505	622	1,460	7,790	8,300	6,860	1,180	3,170	1,510
61	816	2,450	1,100	391	547	697	2,770	12,900	9,540	10,200	1,430	6,160	2,240
67	829	2,460	1,100	393	548	699	2,780	13,000	9,580	10,200	1,440	6,190	2,250
76	1,740	4,030	1,430	519	770	986	4,180	19,400	11,800	15,200	2,370	6,970	2,570
92	1,960	4,530	1,600	582	863	1,120	4,690	21,700	13,300	11,200	2,660	7,820	2,890
115	2,100	4,860	1,720	624	926	1,200	5,040	23,300	14,200	12,000	2,860	8,390	3,040



FIGURE 9. — Scoto upstream from Shadeville. Pictures taken upstream from the Shadeville Bridge, above, April 10, 1938, when the river was in flood with a discharge of about 16,000 second-feet, and below, at low water on August 25, 1938, with an estimated discharge of 108 second-feet. The island visible in the lower picture is entirely covered by flood water in the upper.

Period I.—February 1937 to November 30, 1937—treatment in the old Columbus plant—overloaded trickling filters.

Period II.—December 1, 1937, to July 15, 1938—primary sedimentation in new Columbus plant.

Period III.—July 16, 1938, to July 24, 1939—activated sludge treatment at Columbus, but with periodic discharge of sludge to the river.

In Figure 9 comparative views are shown of the Scioto upstream from Shadeville Bridge in flood stage, with an estimated discharge of 16,000 c. f. s., and at low water, with an estimated discharge of 108 c. f. s.

TIME OF FLOW STUDIES

As the decrease in biochemical oxygen demand and bacterial purification rates have been shown to be a function of time, it is essential that a reasonably accurate estimate be made of the time of flow between sampling points at various stages of the river in order to be able to determine the rates at which natural purification is being accomplished and in order to properly compare the rates obtained with those obtained in other surveys.

As in the previously mentioned surveys on the Ohio, Illinois, and Mississippi Rivers, the time of flow was determined by first computing the mean velocity in a given section of the river by means of the equation $V = \frac{Q}{A}$

where Q = the mean discharge in cubic feet per second,

V = the velocity in feet per second,

A = the mean cross sectional area of the stream in square feet.

In these previous surveys there have been available contour maps of the river with soundings at low water prepared by the U. S. Engineers office of the War Department. As these maps were not available for the Scioto River, it was necessary to survey the river to determine the mean cross sectional area for the sections between sampling points.

Survey to determine mean cross sectional areas.—The funds available did not permit a survey of the complete length of river being studied and the upper portion, between Columbus Sewage Treatment Plant and Red Bridge, above Circleville, a section 25.2 river miles in length, was chosen as being the section where a survey was most desirable. The survey was also limited by time and funds to the channels which would be utilized by a rise of about 10 feet in the river, it being considered that the additional time required to cross section the entire valley was unwarranted in view of the decreasing importance of pollution of the river at higher stages.

Field work.—A line of levels was run up the river from the U. S. Geological Survey bench mark at Circleville to the U. S. Geological

Survey river gage at Columbus. At each point where a cross section was desired temporary bench marks, usually consisting of a nail in a tree, and a stake, were set. Sixty-six such points were chosen, each representing fairly average conditions for a short stretch of the river.

A compass and stadia traverse was then run down the river, locating the river channel, the cross section points and sampling points. A total of 67 cross sections were made in the 25 miles distance. At each cross section point, the river banks and additional channels were cross sectioned by stadia at right angles to the axis of the stream and soundings were made of the stream bed with a sounding line from a boat. In making the soundings, stadia shots were taken at the water's edge on each side of the stream, thus giving the stream width and the soundings taken at estimated tenths of the stream's width. Measurement of the distance of these soundings by stadia or tape hardly seemed justified and it is believed that estimating the distances by tenths of the known river width was more accurate than an estimate of the distance in feet. For soundings quite close to the river bank actual measurement, or an accurate estimate of the distance in feet was desirable and presented no difficulty. It was necessary in a few instances to sound by wading.

In carrying the traverse down river, the surveying party consisted of three men, an instrumentman, rodman and boatman. Work was facilitated by keeping the instrument on one bank of the river and making diagonal shots to the stadia rod on the other side. This usually gave clear shots and avoided the necessity of cutting paths through the high weeds and brush which covered much of the river banks. This method also gave a good definition of the river channel. In order to avoid transferring the instrument across the stream repeatedly, it was necessary to use compass bearings, which were sufficiently accurate for this sort of survey. One short stretch of the river was surveyed by azimuth and stadia and in Figure 10 a plan is shown of two sections of the river, one surveyed by each of these methods.

Computing the mean section areas.—In determining the mean section areas, the stadia traverse was first plotted and a plan of the river channel drawn. The centerline of the river was next drawn in and the distances down river scaled, locating sampling points and cross sections along this centerline. The cross sections were then plotted and a low water profile established from the water surface elevations at the cross sections, beginning and ending at the correlated gage heights at Columbus and Red Bridge respectively. Water surface elevations at a number of stations had been taken while running the level line upstream and as the field work was done during late summer and fall while river flows were low excepting one small rise, the establishment of a low water profile presented no difficulties.

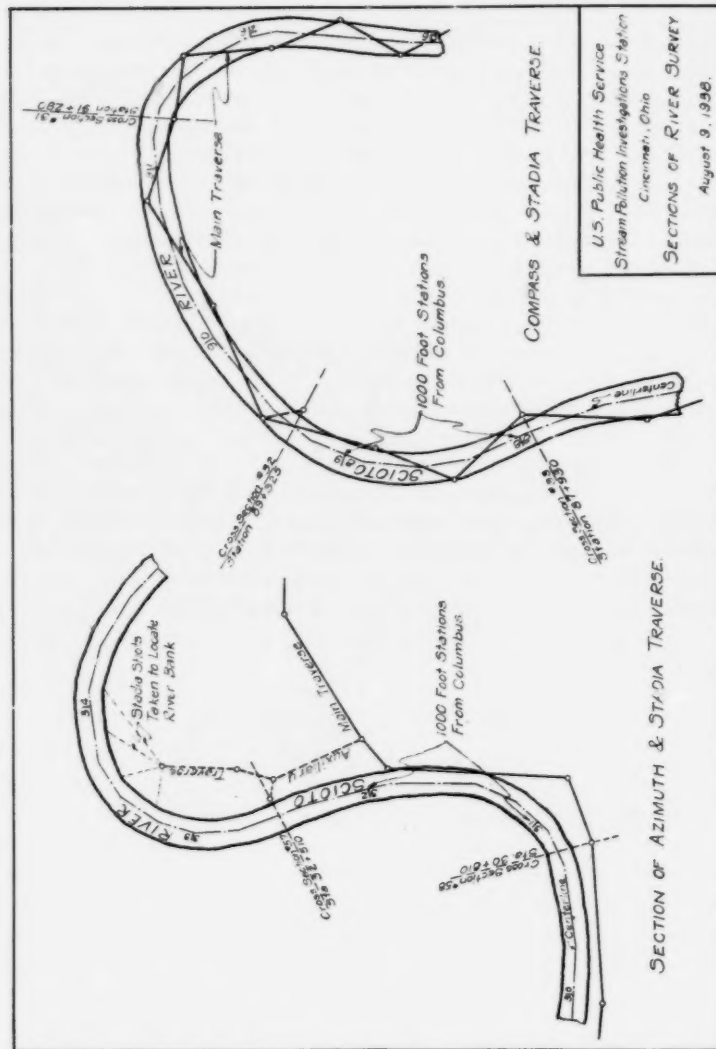


FIGURE 10. PLAN OF TWO TYPICAL SECTIONS OF THE SCIOTO SHOWING METHODS OF SURVEYING.

The low water profile as thus established formed a series of short reaches of varying slope which, over the whole stretch from Columbus to Red Bridge, did not greatly deviate from the average slope of the river between these two gages. In the absence of intermediate gages and any other practical means of determining the water surface curve at higher stages a uniform slope between the two gages was assumed at an arbitrarily high stage and, at intermediate stages, the rise between low water and the assumed uniform slope at high stage was taken as proportional to the rise at the gages.

In determining the mean section areas, the cross sections were plotted and the low water section areas determined by planimetry. For each 2 feet above low water, the additional section area was then determined by scaling the mean river width and adding this to the lower section area, a process of graphical integration. The average section areas for these various stages were then determined for each reach, or river section of uniform low water gradient, and plotted against the elevations of the mid point of that reach, the individual section areas being weighted by the river distance each section covered. From the curves thus constructed, the average section areas were obtained at the estimated rise at this mid point, under the assumed conditions for intermediate stages. The river discharges at these stages were then estimated and a mean velocity for each reach was obtained, from which the time of flow was determined.

Figure 11 is a curve showing the mean velocity in miles per hour between Columbus and Red Bridge as determined by the survey. This chart is for varying discharge in cubic feet per second per square mile of drainage area.

GAGE HEIGHT CORRELATIONS

In the previous studies on the Ohio, Illinois, and Mississippi Rivers gage height correlations were obtained by plotting the gage height at a station against the gage height for that same date at the station to be correlated, a mean curve being drawn through the series of points thus obtained. A method involving less work, though more limited in its application, is given by Thomas (6). In this method a uniform run-off per square mile is assumed throughout the drainage area. On this basis a series of equivalent discharges can be computed for the two gages under consideration and their corresponding stages taken directly from the rating table. However, being based on a uniform run-off throughout the drainage area, the method would be of questionable application on large rivers with widely varying rainfall and run-off characteristics or on rivers where there was appreciable regulation of the stream flow by storage or diversion. Figure 12 shows, as dots, the corresponding daily gage heights at the Red

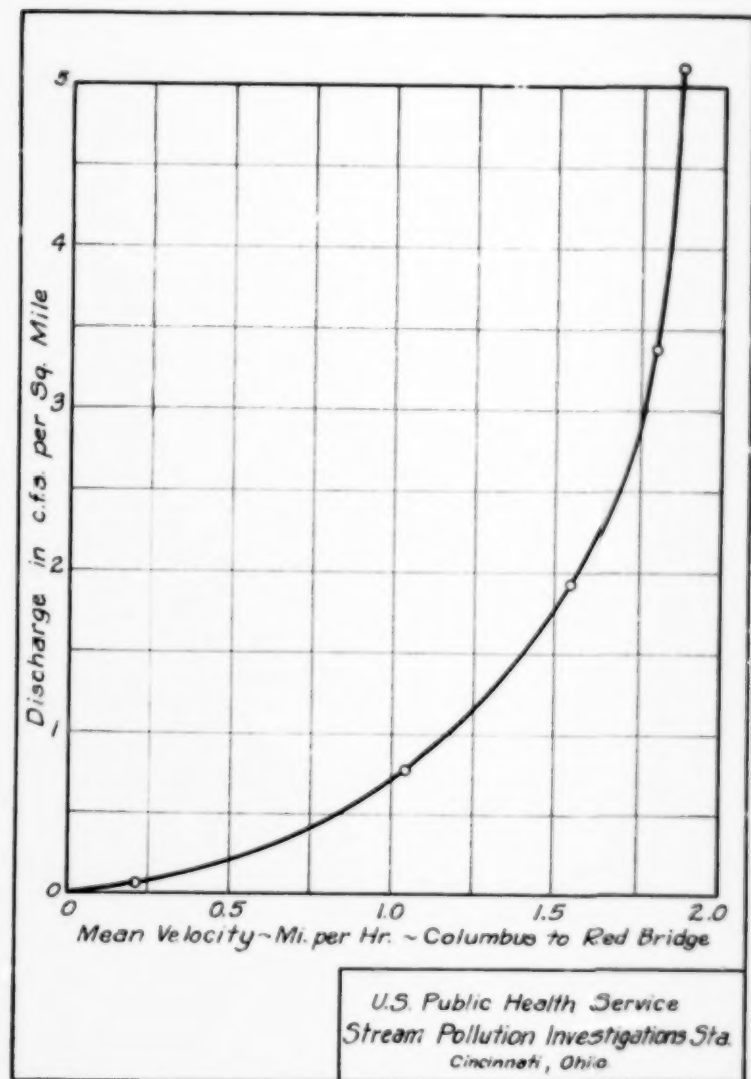


FIGURE 11. VELOCITY AT VARYING DISCHARGE IN THE SHADEVILLE TO RED BRIDGE STRETCH.

Bridge and Columbus gages and a plot of the gage height correlations as determined from their respective rating tables assuming a uniform run-off per square mile of drainage area. It will be noted that either method gives substantially the same curve.

Where the mean annual run-off per square mile at different gaging stations varies appreciably, a gage height correlation curve could be obtained by computing equivalent discharges at each gaging station weighted by the mean annual run-off for that station.

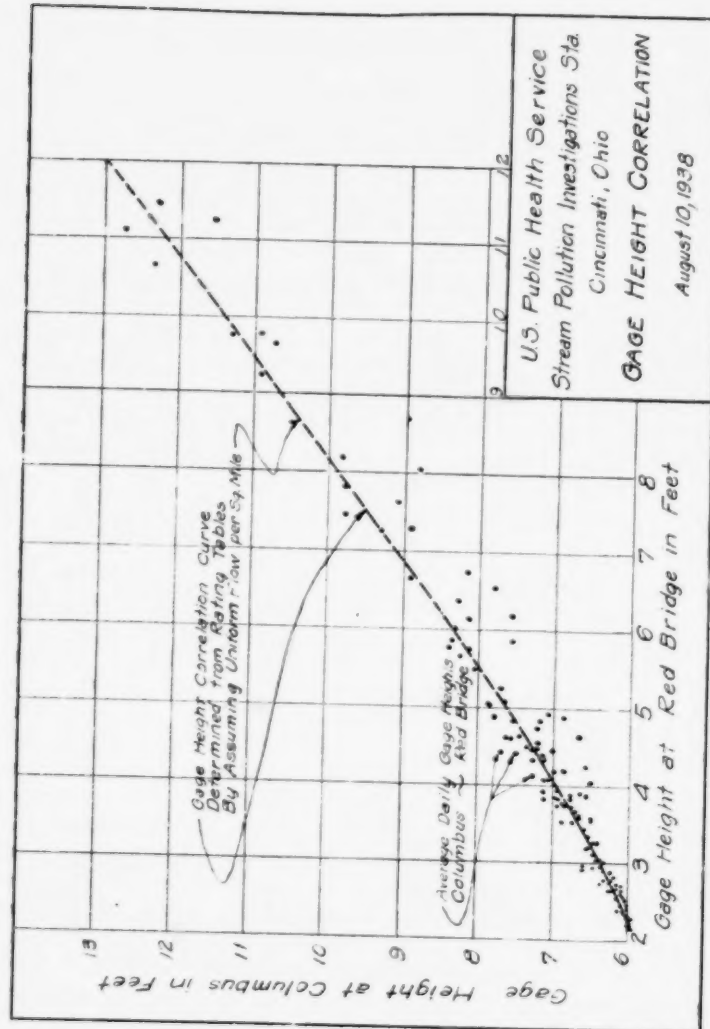


FIGURE 12. COMPARISON OF METHODS OF COMPUTING GAGE HEIGHT CORRELATIONS.

SAMPLING METHODS AND LABORATORY PROCEDURES

The laboratory for the study of the Scioto River was established, through the courtesy of the city of Chillicothe, in the sewage treatment plant of that city. This arrangement had several advantages; the plant is located about midway between the extreme sampling points, it is near Paint Creek, a tributary receiving the wastes from two paper mills located in the city of Chillicothe, it was an ideal situation for measuring the pollution contributed by the city of Chillicothe and in addition was the nearest feasible site to the main laboratory at Cincinnati.

The control laboratory room of the Chillicothe sewage treatment plant was utilized for making the chemical tests on the survey, while the bacteriological equipment was set up on a balcony over the pump room. A portion of these laboratories can be seen in figures 13 and 14.

SAMPLING

There were 13 regular sampling points on the Scioto River and 1 on Paint Creek, covering a 115-mile stretch of the river from Columbus to Lucasville. Additional points were included or deleted as the need was indicated, but the 14 original points were sampled with regularity throughout the survey. These points were selected for the purpose of including the major sources of pollution and of dilution. Samples were collected daily, except Sundays. All regular samples were collected from conveniently located highway or railway bridges, in midchannel. Originally the sample collector made alternate up and down stream trips. When it became apparent that the upstream samples were of much greater significance, sampling downstream was decreased to 1 or 2 days a week. The tributaries were sampled at regular intervals, though less frequently. In addition to the stream samples, 24-hour composite samples from the Chillicothe plant were analyzed every other day. Intermittent samples were analyzed from the sewage treatment plant at Columbus, from the United States Industrial Reformatory, equipped with a septic tank, and the two paper mills located at Chillicothe and from the straw board plant and the sewage treatment plant at Circleville.

Sampling methods were checked by changing the time of collection, by cross sectioning the stream at a given sampling point both laterally and vertically and by sampling hourly throughout a 24-hour period at one sampling point. When a particular stretch of the stream seemed

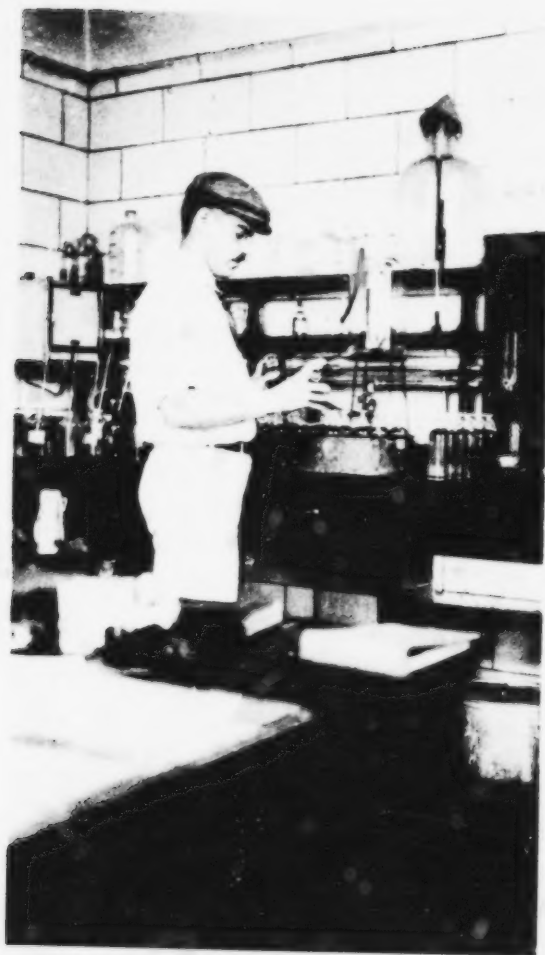


FIGURE 1. Asst. Chemist O. H. Plank making B. O. determination in the B. O. room.

to be of especial interest, a period of intensive sampling was instituted at that section, samples being taken by wading, if necessary.

Automobile transportation was used in the collection of samples. The average time between collection and delivery at the laboratory was about 2 hours. During warm weather the samples were iced while being transported. At the time of collection, the sample collector recorded the date, place, time, and water temperature on a standard form. Space was also provided on this form for any remarks which might seem pertinent, such as the appearance of the river, whether it was in pool, etc. Sample collection is illustrated in figure 15, a photograph of the sampling equipment used.

All samples were collected with a standard sampling can, the construction and use of which is described in Public Health Bulletin No. 171 (3), page 58. Using this sampling can, two D. O. bottles of 300 ml. capacity and a bacteriological sample bottle were filled, the sample in the D. O. bottles having been displaced several times through tubes extending to the bottom of the bottle. The contents of the sampling can were placed in a gallon jug for chemical analysis.

Samples of water and of mud were collected for biological examination, the latter through the use of a mud dredge. These samples were either examined at Chillicothe or were preserved with formaldehyde and shipped to the Cincinnati laboratory for examination.

CHEMICAL ANALYSES

The chemical methods used in the study of the Scioto River were those described in Standard Methods, unless otherwise stated. Daily determinations were made on all samples for hydrogen ion concentration (pH), methyl orange alkalinity, suspended solids, dissolved oxygen and 5-day biochemical oxygen demand (B. O. D.). A B. O. D. series was also incubated on one sample, in rotation, to study the course of the deoxygenation curve. This series consisted of samples to be analyzed after 3, 5, 7, 10, 12, 15, 20, and 25 days incubation.

pH.—pH was determined colorimetrically using the Sanitary District of Chicago's (S. D. C.) portable kit.

Dissolved oxygen.—As nitrites were always present in the Scioto River, the Rideal-Stewart modification of the Winkler procedure was adopted as routine practice. This procedure gave good results except in the presence of suspensions of river muds (7) and on certain samples from Paint Creek. The samples from Paint Creek contained not only an appreciable nitrite content, but also considerable organic material from the wastes of two paper mills. On these samples a "Short Winkler" treatment gave better results. The "Short Winkler" method consists of the addition of 2 ml. of each of the Winkler reagents, shaking for 20 seconds, acidification of the sample without waiting for the precipitate to settle followed by immediate titration. During

the latter part of the survey, the sodium azide modification (8) for the destruction of nitrites was also used in dissolved oxygen determinations. Results obtained by this method were in close agreement with those obtained by the Rideal-Stewart modification (9). The azide method, also, gave more nearly correct results than the Rideal-Stewart modification on Paint Creek samples. While these two modifications were compared on duplicate samples, only the figures obtained by the Rideal-Stewart procedure were used for statistical purposes.

Biochemical oxygen demand.—Procedures for determining 5-day B. O. D. were essentially the same as Standard Methods. Occasionally the samples were found to be supersaturated with respect to oxygen due to low temperatures or to heavy algae growths. In such instances, the samples were warmed slightly if necessary to 25°–30° C., shaken vigorously to remove the excess oxygen and cooled to 20° C.

Due to the high organic content of the river, dilutions were often necessary, usually 50 percent but occasionally as low as 10 percent. Where dilutions were made a synthetic phosphate buffer dilution water containing small amounts of CaCl_2 , MgSO_4 and FeCl_3 was used. A complete description of this one-quarter strength "Formula C" dilution water may be found in Supplement No. 90 to the Public Health Reports (1931).

Nitrogen determinations.—Samples, by stations, were composited for a period of 1 month and were preserved with 2,000 p. p. m. of H_2SO_4 , the total amount of acid being added in the beginning. These composite samples were shipped to the laboratory at Cincinnati where determinations were made for ammonia, nitrates, and organic nitrogen. Free ammonia was determined by direct nesslerization. In the analysis of nitrites and nitrates Standard Methods was followed with the exception that the acid preserved sample was neutralized to a pH of 8–9 and clarified with alumina. The Kjeldahl nitrogen was determined and the organic nitrogen obtained by difference. When it seemed that these determinations were of special significance, ammonia, nitrite, and nitrate determinations were made on fresh samples at the Chillicothe laboratory.

Various other determinations were made intermittently, using standard procedures. Occasional tests were made for iron and for free CO_2 . The possibility of sulphites in Paint Creek was investigated but none were found. Chloride determinations were made several times at Shadeville in an effort to check the stream time of flow data but it was found that the concentration present in the stream was insufficient to give well defined maximum points.

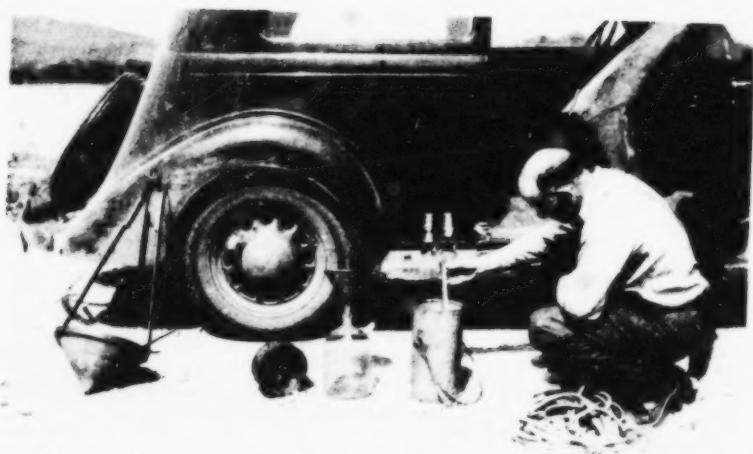


FIGURE 13. Sampling procedure. Tripod dredge at extreme left; rubber bottle for B. O. D. and chemical samples. Sample collector P. A. Feather is in taking temperature of water in sampling can after having first removed D. O. and bacteriological sample bottles visible on running board of car. (from the sampling can)

BACTERIOLOGICAL ANALYSES

Bacteriological examinations made consisted of: (1) Determination of the total number of bacteria which developed on nutrient agar in 24 hours at 37° C., (2) Determination of the coliform index as shown by the results of fermentation tests, using lactose broth for the presumptive test and brilliant green bile lactose broth for partial confirmation, (3) The completed test as given in Standard Methods (1936) was made on one sample from each series of samples collected, rotating the station selected for the completed test in progressive order, to serve as a check on the routine partial confirmation made on all samples, and (4) A special study was made to compare the results obtained with the Standard Methods procedure for the determination of the coliform index with the direct count of the coliform organisms using brilliant green lactose bile agar as the plating medium.

Preparation of glassware and sterilization.—Wide-mouthed ground-glass stoppered bottles of 250 ml. capacity were used in collecting the bacteriological samples. A strip of paper was placed under the stopper to prevent binding and the stopper and bottle neck covered with lead foil. The entire bottle was protected with wrapping paper and sterilized. Pipettes were plugged and placed in cans, then sterilized. Petri dishes were sterilized in special containers. Sterilization was carried out by baking in hot air for 2 hours after the temperature had reached 170° C. Sterilization of dilution water and all media was in the autoclave at 121° C. (15 lbs.) for 15 minutes.

Culture media.—For routine examination, four kinds of culture media were used—nutrient agar, Endo's agar, lactose broth, and brilliant green bile broth. Brilliant green lactose bile agar was used in the special investigation. All media used were from dehydrated stock and careful checks for sterility were maintained throughout the survey. Phosphate buffer dilution water was used, each bottle containing 99 ml.

Plate count.—The method as outlined in Standard Methods, 8th Edition (1936) was essentially the one used in the survey. Two plates were planted with sufficient amount of the sample to give between 25 and 400 colonies per plate. An effort was made to use dilutions which would approximate 200 colonies. A third plate was used in which one-tenth or ten times the amount of the sample utilized in the duplicate was included. In those instances when the conditions of the stream were in doubt both dilutions, viz., one on either side of the duplicate plates, were used. The samples were planted by using 1.0 or 0.1 ml. portions of the sample direct or by making the necessary dilution. One ml. pipettes graduated to 0.1 ml. were used and dilutions for smaller amounts of the sample were made by adding 1 ml. of the previous dilution to 99 ml. of sterile dilution

water. Incubation was in the inverted position at 37° C. for 24 hours.

The colonies which developed were counted over a special illuminated counting device and the standard reading lens used. In recording the results, the following rules were adopted:

1. When the duplicate plates in a series of three gave more than 25, and less than 400 colonies per plate, the third plate was omitted from the average unless it fell between the other two.

2. Where the duplicate plates both showed too many or too few colonies, only the third plate was considered in the average result.

3. Where one of the duplicate plates showed spreaders, clumping, etc., thus giving an obviously erroneous count it was disregarded in recording the average result.

4. When one of the duplicate plates came within the prescribed limits and the other showed too many or too few colonies, both plates were either included in or excluded from the average as follows, except as indicated under 3: (a) where the average of the two duplicate plates fell within the limits, both were included in the average; and (b) when the average of the two fell outside the limits, both were excluded.

5. When more than one set of duplicate plates was made, equal authority was given to each set, providing the number of colonies on the plate fell within the prescribed limits.

In recording results only the first three figures were considered as significant.

Determination of coliform-index.—The partially confirmed test as obtained with brilliant green bile broth was employed in the determination of the coliform index of the samples. For the presumptive test, lactose broth, in Durham fermentation tubes, was used as specified in Standard Methods, 8th Edition (1936). Three portions of each dilution of the sample were planted in lactose broth tubes in three or more decimal dilutions. These dilutions were selected, if possible, so that the lowest dilution would show gas production in all portions, and the highest no gas production.

At the end of 24 hours incubation at 37° C. the tubes were examined and transfers made to brilliant green bile lactose broth of all tubes from the highest dilution which showed gas in any amount. At the same time a transfer was also made to brilliant green bile lactose broth from any other tube of the lower dilutions of the series in which gas production of less than 10 percent was noted. A standard 3 mm. fused platinum loop was used in making these transfers. At the end of 48 hours incubation the presumptive tubes were reexamined and transfers made to brilliant green bile lactose broth from any gas containing tubes which had failed to show gas at the 24 hour period. Gas production, in any amount, in brilliant green bile lactose broth after 24 or 48 hours incubation was considered as evi-

dence of the presence of coliform organisms. The tables as compiled by Hoskins (10) were used for the estimation of the most probable numbers of coliform organisms present in the sample.

The completed test as outlined in Standard Methods was used as a check on the routine partially confirmed results. In progressive rotation one sample from each set collected was carried through the completed test and the same presumptive tubes which were partially confirmed were completed. A small amount of material from the presumptive tube to be tested was streaked on an Endo plate with a platinum needle. After incubation at 37° C. for 24 hours, a positive or suspicious colony was fished to lactose broth and incubated for 24 or 48 hours and if gas was produced a second Endo plate was streaked and the plate incubated. Typical and atypical colonies were fished to agar slants and after incubation a smear made from the growth and stained by Gram's method. The stained smear was then examined for Gram's reaction, purity, and spores.

PRESENTATION OF CHEMICAL AND BACTERIOLOGICAL RESULTS

Previous studies of the natural purification processes in streams have shown that the two major factors in stream purification are: (1) time of flow, and (2) temperature. In summarizing the data for this study, it was decided, therefore, to group all laboratory results at each station on the main river into three temperature classifications, 9.9° C. and below, 10° C. to 19.9° C., and 20° C. and above. To obtain uniformity of stream data with regard to times of flow, the data at each station were further separated into arbitrary groups of stream flow based on a uniform discharge per square mile of drainage area tributary to the sampling station. Results from sampling stations above Chillicothe were further subdivided into three periods according to the varying pollution loads introduced at Columbus as follows: Period 1, February 1937 through November 1937, Columbus sewage treated by overloaded trickling filters; Period 2, December 1937 to July 15, 1938, treatment by plain sedimentation only, at Columbus; and Period 3, July 16, 1938 to the end of the survey, July 24, 1939, Columbus sewage treated by activated sludge process but with the occasional discharge of some excess sludge into the river. The results from the Chillicothe sampling station (61) and from all other stations downstream were summarized according to temperature and time of flow for the entire period of the survey. This was justifiable because no changes occurred in the contributed wastes or in the methods of their disposal in this section and the effect of Columbus sewage on this stretch of the river was very slight in comparison with the increments of pollution at both Chillicothe and Circleville. Moreover, there were too few sets of downstream samples analyzed to obtain satisfactory averages had they been divided further into the three periods of varying pollution at Columbus.

The concept to be obtained, therefore, from this arrangement of the data is the average condition of the river, according to the various analyses, at constant temperature and at uniform, steady flow throughout its length. The arbitrary limits chosen for the divisions in the times of flow were selected to provide for a uniform distribution of samples into each of the various groups. Some idea of the ranges can be obtained from the following table, No. V, which gives the equivalent discharge at several stations for the various range limits.

Table V.—Equivalent discharges at several sampling stations

c. f. s. per square mile	0.077	0.216	0.431	1.234
	c. f. s.	c. f. s.	c. f. s.	c. f. s.
Columbus (3).....	125	350	700	2,000
Circleville (33).....	248	694	1,390	3,960
Chillicothe (61).....	297	832	1,660	4,750
Lucasville (115).....	476	1,330	2,660	7,620

Analyses at Columbus (3) taken when the estimated discharge at that sampling point was between 700 and 2,000 c. f. s. would, therefore, be placed in the same group as samples taken at Lucasville when the river had an estimated discharge of 2,660 to 7,620 c. f. s., or between 0.431 and 1.234 c. f. s. per square mile. Due to progressively higher minimum flows in the river as you go downstream, the number of samples included in the group 0.0 to 0.077 c. f. s. per square mile tended to decrease progressively, there being no recorded discharges in this range below Circleville.

The highest discharge range, 1.234 c. f. s. and above per square mile includes all flood discharges. Inclusion of flood discharges tends to limit the usefulness of this group and to make the averages much more variable than those in the lower ranges. However, as 1.234 c. f. s. per square mile represents flows of about 20 times normal low water, those higher flows are of relatively little importance in considering conditions of pollution. The discharge range limit of 1.234 c. f. s. per square mile represents a rise in the Scioto River of about 3 to 4 feet above normal low water.

In the following 17 tables, tables VI to XXII, the arithmetic averages of all observations made on the Scioto River are presented, grouped according to discharge and temperature for the 1st, 2d, and 3d periods for upstream stations and for the entire survey for stations below Chillicothe.

Table VI.—Summary of analyses, upstream stations, period 1: discharge 0-0.077 c. f. s. per square mile. Arithmetic averages

Station temperature range °C.	Number of samples	Discharge c. f. s. per square mile	Temperature °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coliform
Columbus:										
9.9 and below.....	17	0.063	5.6	17.3	189	7.9	10.21	3.07	10,100	852
10-19.9.....	25	.061	15.4	24.0	178	7.9	5.72	4.00	291,000	1,240
20 and over.....	1	.064	20.0	26.0	178	7.5	5.13	4.69	278,000	430
Shadeville:										
9.9 and below.....	16	.062	7.0	16.3	230	7.4	.88	21.30	583,000	41,700
10-19.9.....	56	.062	15.0	8.3	230	7.5	.39	16.29	1,870,000	30,000
20 and over.....	1	.064	20.5	8.0	236	7.5	.00	14.96	2,190,000	15,000
Commercial Point:										
9.9 and below.....	4	.075	6.0	17.8	237	7.5	2.20	12.57	122,000	14,600
10-19.9.....	12	.073	16.4	10.0	240	7.7	1.31	7.68	635,000	7,120
20 and over.....	9	.073	21.8	11.0	244	7.7	.66	6.11	656,000	2,270

Table VI.—Summary of analyses, upstream stations, period 1: discharge 0-0.077 c. f. s. per square mile. Arithmetic averages—Continued

Station temperature range °C.	Number of samples	Discharge c. f. s. per square mile	Temperature °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coliform
South Bloomfield:										
9.9 and below	3	.076	4.8	10.7	244	7.6	3.25	6.23	1,750	199
10-19.9	7	.067	15.4	8.3	245	7.7	2.35	4.62	107,000	119
20 and over	5	.074	21.5	5.8	267	7.8	1.85	5.56	101,000	38
Red Bridge:										
9.9 and below	0									
10-19.9	4	.076	12.6	20.2	254	7.8	4.54	3.74	44,100	313
20 and over	1	.077	20.0	26.0	258	7.9	3.38	3.40	52,700	93
Circleville:										
9.9 and below	0									
10-19.9	0									
20 and over	0									
Pennsylvania Railroad bridge:										
9.9 and below	0									
10-19.9	0									
20 and over	0									
Kellenburger:										
9.9 and below	0									
10-19.9	0									
20 and over	0									

Table VII.—Summary of analyses, upstream stations, period 1: Discharge 0.078-0.216 c. f. s. per square mile. Arithmetic averages

Station temperature range °C.	Number of samples	Discharge c. f. s. per square mile	Temperature °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coliform
Columbus:										
9.9 and below	2	0.090	9.0	36.5	200	8.3	9.69	2.55	8,580	167
10-19.9	7	.137	11.9	53.8	200	8.1	9.21	4.12	280,000	3,800
20 and over	21	.140	22.7	23.6	165	8.2	6.32	3.24	132,000	371
Shadeville:										
9.9 and below	2	.127	9.5	14.5	212	7.7	4.02	6.53	256,000	5,120
10-19.9	7	.124	12.9	13.6	223	7.5	1.73	13.28	2,670,000	21,100
20 and over	20	.143	23.9	15.2	206	7.6	.42	8.67	3,660,000	21,200
Commercial Point:										
9.9 and below	6	.086	7.8	15.8	237	7.6	2.09	12.78	103,000	9,570
10-19.9	19	.069	13.3	8.7	236	7.7	4.34	8.78	322,000	19,500
20 and over	16	.132	25.4	10.7	212	7.7	1.80	4.79	997,000	3,430
South Bloomfield:										
9.9 and below	8	.085	8.1	12.3	244	7.7	2.17	9.95	104,000	23,100
10-19.9	18	.100	13.8	8.5	233	7.7	2.04	6.15	296,000	10,500
20 and over	15	.136	25.4	10.5	211	7.8	2.16	4.04	192,000	85
Red Bridge:										
9.9 and below	14	.084	6.5	8.3	255	7.7	4.76	4.82	52,400	5,320
10-19.9	24	.098	13.2	20.0	242	7.8	4.70	5.09	69,600	1,190
20 and over	17	.131	24.2	43.0	222	7.8	3.93	4.17	71,400	116
Circleville:										
9.9 and below	14	.087	6.3	9.8	258	7.7	6.32	3.47	28,200	1,080
10-19.9	36	.096	14.1	34.8	247	7.9	5.85	4.72	38,200	407
20 and over	17	.140	24.2	51.9	226	7.9	5.10	4.41	50,700	92
Pennsylvania Railroad bridge:										
9.9 and below	16	.093	6.3	13.9	260	7.7	5.89	9.91	180,400	2,703
10-19.9	34	.096	14.3	36.8	252	7.8	4.19	11.40	2,180,000	14,500
20 and over	16	.112	24.4	47.8	233	7.9	3.30	8.95	2,060,000	1,720
Kellenburger:										
9.9 and below	10	.092	6.2	9.0	268	7.7	4.47	7.59	29,100	528
10-19.9	15	.106	13.7	28.0	255	7.8	4.22	6.09	245,000	2,680
20 and over	11	.119	24.6	34.0	229	7.8	2.66	4.38	193,000	92

Table VIII.—Summary of analyses, upstream stations, period 1: Discharge 0.217-0.431 c. f. s. per square mile. Arithmetic averages

Station temperature range, °C.	Number of samples	Discharge, c. f. s. per square mile	Temperature, °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coliform
Columbus:										
9.9 and below	7	0.338	5.6	48.4	149	8.1	12.68	2.79	12,600	22
10-19.9	7	.375	15.2	25.0	158	8.1	9.68	2.30	7,480	48.1
20 and over	13	.208	24.9	26.5	151	8.3	7.15	2.52	38,300	169
Shadeville:										
9.9 and below	7	.337	5.4	45.4	167	7.6	7.82	12.48	87,000	5,650
10-19.9	7	.376	14.8	24.0	173	7.6	2.78	7.61	90,500	3,320
20 and over	13	.298	23.8	30.6	174	7.6	1.05	6.04	2,140,000	13,800
Commercial Point:										
9.9 and below	5	.380	6.7	18.4	179	7.7	7.90	6.74	25,800	1,790
10-19.9	4	.405	14.9	31.8	178	7.7	3.32	7.84	508,000	13,990
20 and over	19	.312	21.6	33.5	181	7.7	2.22	3.78	353,000	915
South Bloomfield:										
9.9 and below	0									
10-19.9	4	.404	14.8	20.8	191	7.7	3.94	6.82	68,200	718
20 and over	16	.314	21.6	38.8	181	7.7	2.31	3.38	210,000	323
Red Bridge:										
9.9 and below	3	.378	6.7	9.3	188	7.8	8.72	5.45	11,900	430
10-19.9	5	.309	13.9	28.6	196	7.8	4.97	4.16	42,000	244
20 and over	16	.215	21.3	58.0	180	7.7	2.81	3.20	125,000	218
Circleville:										
9.9 and below	3	.384	6.2	13.3	204	7.9	9.10	3.25	8,700	417
10-19.9	4	.330	11.9	29.5	203	7.9	5.18	5.56	48,200	394
20 and over	10	.331	21.1	73.3	198	7.8	3.87	3.58	113,000	189
Pennsylvania Railroad bridge:										
9.9 and below	3	.377	6.2	22.0	290	8.0	8.49	6.76	39,200	540
10-19.9	4	.355	12.0	27.3	214	7.9	5.68	7.20	510,000	1,370
20 and over	17	.333	24.3	90.0	202	7.9	3.49	8.68	326,000	1,000
Kellenburger:										
9.9 and below	0									
10-19.9	0									
20 and over	12	.355	23.7	55.0	208	7.9	3.80	4.26	236,000	127

Table IX.—Summary of analyses, upstream stations, period 1: Discharge 0.432-1.234 c. f. s. per square mile. Arithmetic averages

Station temperature range, °C.	Number of samples	Discharge, c. f. s. per square mile	Temperature, °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coliform
Columbus:										
9.9 and below	10	0.705	5.1	73.0	140	8.0	12.68	2.94	16,700	15.6
10-19.9	9	.673	12.5	59.0	154	8.3	10.11	2.29	12,400	23.4
20 and over	9	.756	23.2	58.1	128	7.9	7.55	1.86	29,100	147
Shadeville:										
9.9 and below	10	.703	5.4	73.3	151	7.7	10.07	8.55	45,300	3,590
10-19.9	9	.672	12.2	62.0	161	7.7	5.40	10.28	422,000	6,890
20 and over	10	.723	22.6	60.8	153	7.5	2.26	6.29	1,940,000	7,370
Commercial Point:										
9.9 and below	13	.767	5.9	70.5	159	7.7	9.77	6.69	31,000	3,120
10-19.9	12	.839	13.6	44.8	162	7.7	5.42	6.70	72,100	1,240
20 and over	12	.779	22.7	95.2	146	7.6	3.25	4.00	897,000	2,920
South Bloomfield:										
9.9 and below	0									
10-19.9	10	.558	14.1	49.3	165	7.8	5.08	4.31	54,100	884
20 and over	12	.782	22.6	154.0	151	7.6	3.02	3.76	942,000	2,090
Red Bridge:										
9.9 and below	14	.735	6.6	91.6	166	7.8	9.20	4.25	30,800	1,070
10-19.9	12	.555	14.0	48.0	169	7.7	5.48	3.57	60,500	276
20 and over	14	.745	22.8	35.2	154	7.6	3.60	3.52	366,000	1,320
Circleville:										
9.9 and below	16	.718	6.5	80.8	181	7.9	9.53	3.49	21,700	515
10-19.9	12	.562	15.0	45.5	183	7.8	6.14	3.53	17,400	198
20 and over	15	.777	22.8	302.0	169	7.8	4.30	3.59	236,000	811
Pennsylvania Railroad bridge:										
9.9 and below	14	.705	6.5	73.0	184	7.9	9.45	5.13	22,400	648
10-19.9	13	.887	14.6	52.8	184	7.9	6.45	5.28	35,900	234
20 and over	14	.799	22.8	351.0	167	7.8	4.27	4.89	358,000	970
Kellenburger:										
9.9 and below	0									
10-19.9	8	.600	16.8	41.0	189	7.8	5.61	4.25	29,400	174
20 and over	10	.738	23.6	170.0	210	7.8	4.98	4.38	240,000	685

Table X.—*Summary of analyses, upstream stations, period 1: Discharge 1.235 c. f. s. per square mile and above. Arithmetic averages*

Station temperature range °C.	Number of sam- ples	Dis- charge c. f. s. per square mile	Tem- pera- ture °C.	Sus- pended solids p. p. m.	Alka- linity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coli- form
Columbus:										
9.9 and below	4	1.51	5.6	78	144	8.0	12.72	1.88	13,400	61.3
10-19.9	3	2.93	13.8	150	103	8.0	10.12	2.97	12,800	204
20 and over	10	4.22	23.7	245	111	7.8	7.22	2.73	70,800	724
Shadeville:										
9.9 and below	4	1.51	5.5	108	151	7.9	11.19	6.65	62,700	3,820
10-19.9	3	2.94	13.5	165	136	7.9	9.01	5.59	41,100	1,930
20 and over	10	4.23	22.9	208	119	7.7	4.90	5.09	422,000	1,660
Commercial Point:										
9.9 and below	2	1.57	3.3	158	140	7.8	11.95	5.84	68,700	1,170
10-19.9	3	2.80	13.7	166	121	7.8	8.81	4.99	50,900	1,810
20 and over	9	3.93	23.2	234	115	7.6	4.84	3.97	346,000	1,560
South Bloomfield:										
9.9 and below	0									
10-19.9	3	2.79	14.0	168	121	7.9	8.40	5.23	46,300	1,380
20 and over	9	3.90	23.1	282	113	7.6	4.42	3.68	414,000	2,760
Red Bridge:										
9.9 and below	3	1.43	3.0	149	141	7.7	11.34	6.03	46,600	1,870
10-19.9	4	2.19	14.2	180	122	7.8	7.41	4.01	51,100	830
20 and over	9	3.71	23.5	276	116	7.6	4.35	3.51	227,600	2,010
Circleville:										
9.9 and below	3	1.40	4.0	160	150	7.7	11.00	5.38	35,300	1,750
10-19.9	4	2.36	14.0	191	132	7.8	7.80	4.65	60,200	1,860
20 and over	8	3.79	23.4	237	115	7.7	4.89	3.43	284,000	1,330
Pennsylvania Rail- road bridge:										
9.9 and below	3	1.40	4.2	168	154	7.7	11.27	5.65	38,900	1,320
10-19.9	4	2.36	13.1	204	135	7.8	7.88	4.98	56,000	1,730
20 and over	7	3.50	23.6	300	125	7.7	4.77	3.86	309,000	1,640
Kellenburger:										
9.9 and below	0									
10-19.9	1	1.34	15.0	146	144	7.8	7.58	3.76	28,000	2,400
20 and over	8	3.10	23.5	477	130	7.7	4.50	4.20	236,000	830

Table XI.—Summary of analyses, upstream stations, period 2: Discharge 0-0.077 c. f. s. per square mile. Arithmetic averages

[illegible]

Table XII.—Summary of analyses, upstream stations, period 2: Discharge 0.078-0.216 c. f. s. per square mile. Arithmetic average

Station temperature range °C.	Number of samples	Discharge c. f. s. per square mile	Temperature °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coliform
Columbus:										
9.9 and below	16	0.139	2.3	12.0	181	7.9	12.29	2.40	8,660	306
10-19.9	7	.141	16.4	19.7	181	8.1	8.91	2.97	1,840	44.5
20 and over	7	.164	22.1	22.8	174	8.2	7.73	2.44	6,100	83.7
Shadeville:										
9.9 and below	16	.139	3.9	20.8	208	7.5	3.04	29.40	202,000	16,700
10-19.9	9	.150	16.6	27.0	219	7.5	0.00	23.33	2,050,000	73,800
20 and over	5	.158	21.6	23.0	207	7.5	.22	17.87	2,520,000	41,700
Commercial Point:										
9.9 and below	15	.144	4.7	14.2	225	7.5	3.14	17.67	132,000	22,400
10-19.9	6	.183	17.7	17.2	223	7.6	.20	11.09	1,330,000	16,400
20 and over	2	.164	24.5	11.5	203	7.7	.80	6.82	1,095,000	5,409
South Bloomfield:										
9.9 and below	15	.145	4.7	10.2	231	7.5	2.84	13.67	132,000	14,800
10-19.9	5	.182	17.6	14.4	245	7.7	1.09	8.65	833,000	12,400
20 and over	3	.177	23.0	18.3	215	7.7	.92	7.64	1,260,000	12,800
Red Bridge:										
9.9 and below	17	.126	2.8	14.0	248	7.6	4.14	9.02	79,500	19,800
10-19.9	6	.199	17.2	16.2	240	7.7	2.65	4.52	186,000	4,300
20 and over	2	.179	23.8	43.0	220	7.7	2.49	3.87	59,100	93
Circleville:										
9.9 and below	15	.122	2.2	8.6	257	7.6	5.71	7.65	69,200	15,100
10-19.9	3	.212	15.5	23.0	241	7.7	4.79	3.30	184,000	4,060
20 and over	2	.197	23.8	48.5	227	7.8	3.84	3.41	38,600	68
Pennsylvania Railroad bridge:										
9.9 and below	15	.122	2.0	13.3	261	7.6	5.64	12.22	97,500	7,650
10-19.9	3	.212	16.2	30.0	253	7.9	5.02	8.61	180,000	1,820
20 and over	2	.197	24.3	38.5	228	7.7	3.00	8.31	309,000	795
Kellenburger:										
9.9 and below	8	.117	1.4	15.9	270	7.6	5.89	9.47	47,600	3,030
10-19.9	1	.210	16.0	21.0	254	7.9	4.97	5.45	121,000	1,500
20 and over	2	.200	21.0	22.0	232	7.7	4.03	6.13	90,800	43

Table XIII.—Summary of analyses, upstream stations, period 2: Discharge 0.217-0.431 c. f. s. per square mile. Arithmetic average

Station temperature range °C.	Number of samples	Discharge c. f. s. per square mile	Temperature °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coliform
Columbus:										
9.9 and below	7	0.336	2.4	56.9	143	7.8	13.02	6.48	20,900	840
10-19.9	7	.207	16.5	23.7	164	8.2	9.30	1.83	3,080	32.2
20 and over	4	.257	21.8	18.0	176	8.0	7.73	1.94	7,840	124
Shadeville:										
9.9 and below	7	.336	3.1	61.6	167	7.5	8.35	30.85	134,000	12,100
10-19.9	8	.238	15.9	16.2	190	7.4	.85	10.35	305,000	13,000
20 and over	3	.262	21.0	23.7	204	7.4	.12	13.80	1,860,000	23,400
Commercial Point:										
9.9 and below	8	.310	4.3	26.5	193	7.6	6.87	16.10	87,700	14,500
10-19.9	8	.316	16.9	17.3	205	7.6	2.88	6.12	136,000	5,580
20 and over	8	.288	21.5	15.5	210	7.6	1.84	7.10	706,000	13,400
South Bloomfield:										
9.9 and below	8	.311	4.3	21.8	197	7.6	6.48	11.85	85,900	5,670
10-19.9	8	.318	17.3	13.7	204	7.6	2.93	5.07	67,900	1,560
20 and over	8	.291	21.7	16.5	212	7.6	1.82	6.42	541,000	18,600
Red Bridge:										
9.9 and below	9	.284	3.6	25.0	209	7.7	7.89	5.46	15,500	955
10-19.9	8	.334	16.6	19.1	213	7.6	3.93	5.55	27,700	1,850
20 and over	8	.310	21.2	18.7	213	7.7	3.36	4.70	224,000	689
Circleville:										
9.9 and below	11	.280	3.5	15.2	221	7.7	8.05	4.41	11,100	1,130
10-19.9	11	.327	17.1	22.7	226	7.7	4.73	4.30	60,300	2,220
20 and over	8	.316	21.1	47.3	221	7.7	4.15	3.67	425,000	3,220
Pennsylvania Railroad bridge:										
9.9 and below	11	.280	3.5	16.4	226	7.7	8.16	8.43	33,600	1,222
10-19.9	10	.325	17.2	22.6	231	7.7	5.02	5.68	99,500	1,640
20 and over	9	.319	21.2	32.4	226	7.8	4.69	5.57	110,000	707
Kellenburger:										
9.9 and below	7	.270	3.9	7.0	231	7.7	7.68	6.49	11,400	445
10-19.9	6	.310	17.3	26.0	234	7.7	5.30	5.38	82,000	287
20 and over	7	.339	21.5	25.0	233	7.8	4.89	4.69	110,000	41.7

Table XIV.—Summary of analyses, upstream stations, period 2: Discharge 0.432-1.234 c. f. s. per square mile. Arithmetic average

Station temperature range °C.	Number of samples	Discharge c. f. s. per square mile	Temperature °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coliform
Columbus:										
9.9 and below	26	0.808	3.1	58	147	7.8	13.00	2.10	6,000	211
10-19.9	11	.808	15.0	84	136	7.7	9.45	2.65	9,970	968
20 and over	12	.712	22.2	34.6	168	8.1	7.85	2.62	6,020	74
Shadeville:										
9.9 and below	25	.800	3.2	66	155	7.6	11.02	10.37	46,300	2,990
10-19.9	14	.778	14.7	80	155	7.5	5.41	8.47	225,000	6,330
20 and over	11	.745	21.5	42.4	180	7.6	2.74	8.97	489,000	12,300
Commercial Point:										
9.9 and below	18	.807	3.4	69.8	150	7.6	11.12	8.96	30,400	3,150
10-19.9	5	.857	15.7	54	156	7.5	5.02	4.88	71,100	1,760
20 and over	10	.735	22.1	33.1	179	7.6	2.53	6.18	409,000	14,700
South Bloomfield:										
9.9 and below	25	.825	3.4	63	152	7.6	10.70	8.20	30,700	2,120
10-19.9	10	.857	15.4	53.0	163	7.5	5.22	4.31	44,600	2,340
20 and over	10	.741	22.1	28.3	179	7.6	2.99	4.75	79,600	1,780
Red Bridge:										
9.9 and below	16	.745	3.7	69	157	7.6	10.76	6.21	23,800	1,180
10-19.9	2	.663	16.5	69	183	7.5	5.94	2.95	9,800	233
20 and over	11	.788	22.1	55.5	178	7.6	3.65	3.59	41,800	772
Circleville:										
9.9 and below	16	.749	3.0	67.6	168	7.6	10.96	5.02	24,400	1,360
10-19.9	3	.872	16.8	124	187	7.6	6.01	2.84	12,700	880
20 and over	10	.802	22.1	79.2	184	7.6	4.45	2.48	27,600	221
Pennsylvania Railroad bridge:										
9.9 and below	25	.849	3.9	59.3	175	7.7	10.90	4.87	25,900	1,220
10-19.9	8	.840	15.4	80	190	7.7	7.02	2.54	14,800	285
20 and over	11	.838	21.9	96.6	187	7.7	4.71	4.06	63,100	307
Kellenburger:										
9.9 and below	11	.845	3.7	74	174	7.6	10.43	5.53	24,400	523
10-19.9	2	.818	15.5	64	196	7.7	6.84	3.75	13,400	260
20 and over	7	.821	22.3	93	189	7.7	4.42	4.05	30,800	326

Table XV.—Summary of analyses, upstream stations, period 2: Discharge 1.235 c. f. s. per square miles and above. Arithmetic average

Station temperature range °C.	Number of samples	Discharge c. f. s. per square mile	Temperature °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coliform
Columbus:										
9.9 and below	26	4.60	4.5	199	125	7.6	12.64	2.48	12,100	222
10-19.9	8	2.41	12.5	140	126	7.6	10.18	2.52	7,510	193
20 and over	0									
Shadeville:										
9.9 and below	26	4.59	4.8	206	125	7.6	11.68	7.72	41,500	1,620
10-19.9	8	2.42	14.2	158	134	7.5	8.99	4.33	34,300	1,280
20 and over	0									
Commercial Point:										
9.9 and below	10	2.37	3.3	271	129	7.7	11.21	13.56	59,600	3,820
10-19.9	3	2.84	16.2	164	129	7.5	7.14	4.93	69,000	1,250
20 and over	2	1.43	20.5	64	161	7.6	3.48	8.12	174,000	1,660
South Bloomfield:										
9.9 and below	29	4.01	5.0	227	119	7.5	10.86	6.48	34,600	1,330
10-19.9	11	2.43	12.9	156	129	7.5	7.94	4.39	40,500	1,630
20 and over	2	1.45	20.5	56	157	7.6	3.12	5.58	47,500	2,680
Red Bridge:										
9.9 and below	11	3.06	4.0	334	122	7.5	11.10	6.42	41,400	1,220
10-19.9	4	2.88	15.2	143	124	7.5	6.78	4.13	47,300	1,680
20 and over	2	1.53	20.5	91.5	153	7.6	3.78	3.80	39,900	580
Circleville:										
9.9 and below	12	2.73	3.4	403	130	7.5	11.48	7.02	43,200	1,270
10-19.9	6	2.77	14.0	141	140	7.5	7.95	3.62	36,400	500
20 and over	2	1.64	20.5	98	154	7.6	4.27	3.69	40,000	670
Pennsylvania Railroad bridge:										
9.9 and below	30	3.76	5.1	317	129	7.5	10.94	4.55	34,000	1,500
10-19.9	12	2.58	13.4	205	146	7.6	8.10	3.86	47,000	722
20 and over	2	1.65	21.0	110	164	7.6	4.47	4.64	61,500	670
Kellenburger:										
9.9 and below	9	3.64	4.5	318	131	7.6	11.31	4.21	24,800	428
10-19.9	2	3.28	15.2	197	133	7.6	7.19	3.23	32,100	445
20 and over	2	1.64	20.2	188	155	7.7	4.60	4.53	60,200	460

Table XVI.—Summary of analyses, upstream stations, period 3: Discharge 0-0.077 c. f. s. per square mile. Arithmetic average

Station temperature range °C.	Number of samples	Discharge c. f. s. per square mile	Temperature °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coli-form
Columbus:										
9.9 and below.....	5	0.052	8.4	21	210	7.8	7.43	6.17	108,400	1,910
10-19.9.....	24	.060	14.8	26	181	7.6	5.54	5.09	88,800	10,700
20 and over.....	10	.056	25.0	30	175	7.7	4.52	3.64	64,400	262
Shadeville:										
9.9 and below.....	2	.045	8.5	5.0	206	7.5	5.50	5.96	11,000	24
10-19.9.....	27	.050	15.0	6	220	7.5	2.61	3.14	262,000	1,490
20 and over.....	11	.056	24.1	15	225	7.7	5.01	4.66	289,000	117
Commercial Point:										
9.9 and below.....	0									
10-19.9.....	8	.073	15.0	10	234	7.6	5.40	3.66	44,400	72
20 and over.....	5	.075	25.6	17	234	7.7	4.80	4.84	199,000	6.0
South Bloomfield:										
9.9 and below.....	0									
10-19.9.....	6	.073	12.7	6.5	225	7.6	4.65	2.88	7,700	18.7
20 and over.....	3	.075	23.0	13	231	7.6	4.05	4.66	60,500	8.6
Red Bridge:										
9.9 and below.....	1	.077	8.5	10	246	7.7	7.24	2.02	7,500	4.3
10-19.9.....	0									
20 and over.....	0									
Circleville:										
9.9 and below.....	0									
10-19.9.....	0									
20 and over.....	0									
Pennsylvania Railroad bridge:										
9.9 and below.....	0									
10-19.9.....	0									
20 and over.....	0									
Kellenberger:										
9.9 and below.....	0									
10-19.9.....	0									
20 and over.....	0									

Table XVII.—Summary of analyses, upstream stations, period 3: Discharge 0.078-0.216 c. f. s. per square mile. Arithmetic average

Station temperature range °C.	Number of samples	Discharge c. f. s. per square mile	Temperature °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coli-form
Columbus:										
9.9 and below.....	24	0.130	3.6	12	178	8.1	12.53	1.68	1,820	65
10-19.9.....	9	.122	16.9	36	159	7.9	7.28	2.39	8,950	78
20 and over.....	34	.134	25.0	28	157	7.9	6.42	2.41	33,800	162
Shadeville:										
9.9 and below.....	23	.129	4.8	10	206	7.5	4.85	13.91	129,000	13,100
10-19.9.....	10	.124	16.2	8.6	206	7.5	2.31	5.46	454,000	5,270
20 and over.....	34	.134	24.0	16	183	7.6	2.35	5.06	1,100,000	2,930
Commercial Point:										
9.9 and below.....	21	.153	6.0	18	211	7.6	5.80	6.95	48,800	3,340
10-19.9.....	18	.167	17.0	18	227	7.6	4.16	3.88	156,000	860
20 and over.....	45	.137	25.1	17	207	7.6	3.65	4.65	78,300	258
South Bloomfield:										
9.9 and below.....	20	.154	5.8	15	211	7.6	5.93	4.50	11,100	1,270
10-19.9.....	26	.163	16.5	15	222	7.6	3.64	3.64	34,800	68
20 and over.....	41	.140	25.2	17	207	7.7	4.19	3.89	42,700	147
Red Bridge:										
9.9 and below.....	19	.149	5.0	12	219	7.6	7.67	2.82	5,070	392
10-19.9.....	33	.105	15.6	27	236	7.7	5.77	3.08	18,600	67
20 and over.....	30	.148	24.9	40	213	7.8	6.16	4.32	22,800	162
Circleville:										
9.9 and below.....	19	.151	4.7	12	220	7.7	8.93	2.17	4,620	355
10-19.9.....	31	.107	15.2	30	242	7.7	6.68	2.81	17,800	102
20 and over.....	34	.150	24.7	45	223	7.9	6.88	3.58	17,000	120
Pennsylvania Railroad bridge:										
9.9 and below.....	10	.152	5.2	14	233	7.7	8.62	8.98	99,200	1,850
10-19.9.....	30	.107	15.4	33	253	7.7	4.46	14.08	338,000	1,750
20 and over.....	35	.149	24.8	50	231	7.8	4.41	9.18	1,160,000	3,380
Kellenberger:										
9.9 and below.....	9	.147	5.6	16	236	7.7	7.12	4.94	7,410	840
10-19.9.....	17	.108	15.6	21	257	7.7	3.35	4.52	144,000	430
20 and over.....	21	.150	24.9	28	236	7.8	4.66	4.70	112,000	284

**Table XVIII.—Summary of analyses, upstream stations, period 3:
Discharge 0.217-0.431 c. f. s. per square mile. Arithmetic average**

Station temperature range °C.	Num- ber of sam- ples	Dis- charge c. f. s. per square mile	Tem- pera- ture °C.	Sus- pended solids p. p. m.	Alka- linity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coli- form
Columbus:										
9.9 and below	4	0.311	2.9	18	176	8.1	13.05	1.89	482	10.2
10-19.9	4	.301	16.0	25	159	8.3	10.30	2.06	1,110	9.7
20 and over	8	.307	26.0	49	151	7.8	6.75	2.02	28,000	181
Shadeville:										
9.9 and below	4	.311	3.4	70	197	7.6	7.92	19.02	106,000	5,680
10-19.9	4	.301	15.1	10.5	193	7.6	2.89	5.50	43,100	2,770
20 and over	8	.307	24.8	33	173	7.6	2.44	4.11	301,000	1,320
Commercial Point:										
9.9 and below	5	.296	3.6	20	195	7.7	9.57	6.89	37,900	3,470
10-19.9	4	.311	15.1	21	196	7.6	5.07	4.07	16,600	738
20 and over	12	.298	21.7	31	179	7.6	3.26	3.19	336,000	1,110
South Bloomfield:										
9.9 and below	5	.298	3.7	20	194	7.7	9.60	6.51	23,900	1,420
10-19.9	4	.314	15.4	14	200	7.6	5.02	4.65	12,400	249
20 and over	13	.294	25.0	30	182	7.6	3.21	3.13	56,500	228
Red Bridge:										
9.9 and below	8	.281	3.2	34	197	7.6	8.79	4.53	25,100	1,120
10-19.9	5	.311	14.5	60	201	7.7	6.48	4.10	29,700	671
20 and over	12	.302	24.7	55	185	7.7	4.14	3.06	34,800	155
Circleville:										
9.9 and below	9	.279	3.3	34	205	7.7	8.96	3.37	27,900	1,040
10-19.9	6	.301	15.7	47	213	7.7	6.50	2.04	13,200	215
20 and over	16	.285	24.3	215	199	7.7	4.88	2.72	92,900	766
Pennsylvania Railroad bridge:										
9.9 and below	9	.279	4.2	33	205	7.7	9.14	6.12	46,900	2,900
10-19.9	5	.318	16.3	63	215	7.7	6.60	7.20	89,000	451
20 and over	18	.290	24.7	160	207	7.7	4.11	6.47	328,000	554
Kellenberger:										
9.9 and below	2	.257	3.5	50	220	7.7	8.08	2.11	13,000	305
10-19.9	4	.326	15.6	34	200	7.6	6.54	4.20	65,800	320
20 and over	10	.264	24.0	30	217	7.7	4.18	4.05	155,000	285

**Table XIX.—Summary of analyses, upstream stations, period 3: Discharge
0.432-1.234 c. f. s. per square mile. Arithmetic average**

Station temperature range °C.	Num- ber of sam- ples	Dis- charge c. f. s. per square mile	Tem- pera- ture °C.	Sus- pended solids p. p. m.	Alka- linity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coli- form
Columbus:										
9.9 and below	18	0.942	5.9	96	120	7.7	12.86	1.91	6,840	184
10-19.9	6	.637	14.6	163	142	7.7	9.65	5.26	227,000	1,860
20 and over	16	.757	24.8	100	134	7.8	6.92	3.10	118,000	2,050
Shadeville:										
9.9 and below	17	.958	5.5	102	138	7.6	11.47	5.27	21,900	1,600
10-19.9	7	.610	13.7	78	153	7.5	6.47	4.94	107,000	3,170
20 and over	16	.760	24.5	158	143	7.5	3.23	4.80	407,000	2,700
Commercial Point:										
9.9 and below	10	.948	5.8	86	146	7.6	10.50	5.80	23,400	780
10-19.9	7	.672	13.7	55	162	7.6	7.13	4.00	34,300	2,260
20 and over	21	.738	25.2	142	145	7.6	3.68	3.62	200,000	1,950
South Bloomfield:										
9.9 and below	10	.955	5.8	89	150	7.6	10.24	5.57	15,500	1,600
10-19.9	7	.677	13.4	63	166	7.6	7.28	3.42	17,100	1,050
20 and over	21	.738	25.0	128	149	7.6	3.47	3.69	242,000	1,120
Red Bridge:										
9.9 and below	8	.935	5.4	114	156	7.6	10.44	3.50	12,400	302
10-19.9	8	.710	14.5	132	172	7.7	7.22	3.28	50,000	792
20 and over	21	.725	25.3	294	146	7.6	3.80	2.71	161,000	1,120
Circleville:										
9.9 and below	8	.797	5.1	85	170	7.7	10.63	3.07	13,700	133
10-19.9	7	.776	14.1	131	179	7.7	7.16	2.42	43,500	472
20 and over	23	.722	24.9	228	150	7.6	4.23	2.67	105,000	416
Pennsylvania Railroad bridge:										
9.9 and below	7	.828	5.1	79	176	7.7	10.89	4.50	16,200	406
10-19.9	8	.748	14.8	118	184	7.7	7.46	4.48	43,800	579
20 and over	22	.749	25.2	233	156	7.7	4.16	4.14	179,000	872
Kellenberger:										
9.9 and below	3	.684	3.3	92	177	7.7	10.69	5.23	20,300	313
10-19.9	5	.730	13.8	72	189	7.7	7.63	3.93	11,100	545
20 and over	17	.674	25.1	120	160	7.6	4.00	2.67	162,000	296

Table XX.—Summary of analyses, upstream stations, period 3: Discharge 1.235 c. f. s. per square mile and above. Arithmetic average

Station temperature range °C.	Number of samples	Discharge c. f. s. per square mile	Temperature °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coliform
Columbus:										
9.9 and below.....	27	3.60	5.6	189	114	7.6	12.75	2.24	12,100	127
10-19.9.....	2	3.48	11.2	111	117	7.7	11.42	3.04	5,100	29
20 and over.....	8	3.50	24.3	159	126	7.7	7.28	1.76	37,000	294
Shadysville:										
9.9 and below.....	26	3.62	5.6	251	120	7.6	11.70	4.60	35,100	2,800
10-19.9.....	3	3.33	10.7	336	121	7.7	10.20	4.64	29,600	963
20 and over.....	8	3.50	24.4	156	128	7.6	5.80	3.07	98,000	2,000
Commercial Point:										
9.9 and below.....	35	2.89	5.7	219	120	7.6	11.25	4.36	27,700	808
10-19.9.....	2	4.19	12.0	109	122	7.7	9.92	3.44	11,300	251
20 and over.....	7	3.36	23.7	181	128	7.7	5.52	2.64	122,000	829
South Bloomfield:										
9.9 and below.....	34	2.89	5.6	228	121	7.6	11.41	4.54	22,300	690
10-19.9.....	3	3.82	10.3	127	125	7.6	9.79	3.60	8,810	1,190
20 and over.....	7	3.34	23.7	180	129	7.6	5.09	2.92	147,000	1,550
Red Bridge:										
9.9 and below.....	35	2.80	5.6	276	241	7.6	11.24	4.04	23,100	780
10-19.9.....	4	3.14	11.2	140	131	7.6	9.92	2.88	10,800	492
20 and over.....	7	3.23	24.0	228	129	7.6	4.64	2.77	278,000	930
Circleville:										
9.9 and below.....	39	2.63	5.2	221	135	7.6	11.24	3.17	21,700	542
10-19.9.....	2	4.70	12.5	163	123	7.6	9.66	2.68	16,300	1,220
20 and over.....	6	3.49	23.9	252	128	7.6	4.16	3.10	281,000	672
Pennsylvania Railroad bridge:										
9.9 and below.....	37	2.67	5.8	231	141	7.7	11.20	4.19	22,500	903
10-19.9.....	4	3.30	11.4	119	141	7.6	9.94	3.42	10,100	342
20 and over.....	6	3.39	24.0	235	132	7.6	4.80	3.37	216,000	845
Kellenburger:										
9.9 and below.....	19	2.58	6.2	237	147	7.6	10.83	3.38	24,900	146
10-19.9.....	2	4.43	12.5	97	161	7.7	9.60	2.82	6,320	93
20 and over.....	2	3.31	24.0	144	141	7.6	2.91	2.99	128,000	497

Table XXI.—Summary of analyses, downstream stations: Discharge 0.078-0.216 and 0.217-0.317 c. f. s. per square mile. Arithmetic average

Station temperature range °C.	Number of sam- ples	Dis- charge c. f. s. per square mile	Tem- perature °C.	Sus- pended solids p. p. m.	Alka- linity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Col- form
DISCHARGE 0.078-0.216 C. F. S. PER SQ. MILE										
Chillicothe:										
9.9 and below.....	15	0.148	4.1	13.1	236	7.7	9.34	4.22	6,270	281
10-19.9.....	17	.105	14.6	18.5	247	7.9	8.23	4.35	18,600	339
20 and over.....	17	.155	24.6	34.5	238	8.1	7.92	4.58	24,500	278
Kilgore:										
9.9 and below.....	15	.144	3.7	13.0	242	7.7	9.70	3.55	9,500	379
10-19.9.....	17	.109	14.3	16.0	270	8.0	8.50	4.01	28,800	477
20 and over.....	15	.150	24.8	37.0	236	8.1	7.94	4.07	34,900	711
Highby:										
9.9 and below.....	11	.131	4.0	11.0	252	7.7	9.21	5.97	4,460	312
10-19.9.....	17	.116	14.5	37.0	290	8.0	6.13	6.04	284,000	301
20 and over.....	11	.160	24.0	46.0	241	8.1	5.78	5.35	425,000	924
Waverly:										
9.9 and below.....	13	.126	4.5	9.8	246	7.8	9.60	3.63	18,600	125
10-19.9.....	15	.120	14.9	18.0	247	8.1	8.50	4.08	26,300	25.2
20 and over.....	10	.155	23.9	32.0	239	8.2	6.88	3.92	72,800	47
Lucasville:										
9.9 and below.....	13	.126	3.8	9.3	239	7.9	11.31	2.68	3,010	10.3
10-19.9.....	14	.113	14.9	16.0	244	8.2	9.20	3.30	19,100	6.8
20 and over.....	10	.155	24.2	35.0	232	8.2	7.02	3.36	16,800	8.5

Table XXI.—Summary of analyses, downstream stations: Discharge 0.078–0.216 and 0.217–0.431 c. f. s. per sq. mile. Arithmetic average—Con.

Station temperature range °C.	Number of samples	Discharge c. f. s. per square mile	Temperature °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37°C. count	Coliform
DISCHARGE 0.217-0.431 C. F. S. PER SQ. MILE										
Chillicothe:										
9.9 and below.....	9	.324	4.6	20.1	216	7.8	9.46	4.21	5,670	144
10-19.9.....	6	.292	15.4	17.7	229	7.9	8.40	4.32	5,690	50.5
20 and over.....	27	.329	23.3	81.0	212	7.9	6.07	3.65	47,500	138
Kilgore:										
9.9 and below.....	9	.323	4.9	22.0	219	7.7	9.87	3.96	6,450	406
10-19.9.....	6	.291	15.8	20.0	232	8.0	9.35	4.07	5,000	138
20 and over.....	16	.316	23.3	100.0	211	8.1	6.97	3.49	33,400	230
Higby:										
9.9 and below.....	9	.282	5.4	22.0	231	7.8	9.87	4.89	8,350	212
10-19.9.....	4	.293	15.5	22.0	244	8.1	8.90	5.21	15,700	406
20 and over.....	23	.327	23.5	46.2	210	8.0	5.86	3.92	219,000	379
Waverly:										
9.9 and below.....	9	.282	5.2	22.0	209	7.6	10.21	3.14	4,870	128
10-19.9.....	4	.301	15.2	23.0	225	8.1	9.86	3.77	13,800	56
20 and over.....	17	.323	23.8	77.0	206	8.1	6.73	2.98	74,100	74
Lucasville:										
9.9 and below.....	9	.282	4.9	20.0	198	7.8	11.07	2.37	2,980	49
10-19.9.....	5	.284	14.6	24.0	231	8.1	9.99	3.25	8,920	9.7
20 and over.....	17	.323	23.8	81.0	205	8.1	7.43	2.89	28,500	24

Table XXII.—Summary of analyses, downstream stations: Discharge 0.432–1.234 and 1.235 and above c. f. s. per square mile. Arithmetic average

Station temperature range °C.	Number of sam- ples	Dis- charge c. f. s. per square mile	Tem- pera- ture °C.	Sus- pended solids p. p. m.	Alka- linity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coli form
DISCHARGE 0.432-1.234 C. F. S. PER SQ. MILE										
Chillicothe:										
9.9 and below.....	27	0.791	6.0	81	181	7.8	10.37	3.48	23,800	268
10-19.9.....	21	.638	14.7	45	194	7.9	7.35	3.55	14,300	128
20 and over.....	16	.663	23.4	218	181	7.8	4.93	3.40	99,800	246
Kilgore:										
9.9 and below.....	20	.755	5.6	68	184	7.8	10.43	3.40	11,800	271
10-19.9.....	23	.650	14.0	48	194	7.9	7.77	2.89	10,500	162
20 and over.....	16	.662	23.2	186	180	7.8	5.40	2.94	68,000	327
Higby:										
9.9 and below.....	23	.741	5.2	70	192	7.8	10.67	3.56	13,600	194
10-19.9.....	25	.661	14.1	42	199	7.9	7.90	3.07	17,000	133
20 and over.....	21	.658	23.0	183	192	7.9	5.48	2.86	116,000	265
Waverly:										
9.9 and below.....	27	.762	5.4	74	178	7.8	10.89	3.00	10,300	261
10-19.9.....	25	.637	14.6	56	184	7.9	8.19	2.41	14,700	120
20 and over.....	21	.655	23.4	196	186	7.9	6.07	2.57	86,400	185
Lucasville:										
9.9 and below.....	26	.733	5.1	86	169	7.8	11.62	2.57	8,840	163
10-19.9.....	26	.671	14.2	68	178	8.0	8.69	2.16	11,900	89
20 and over.....	21	.687	23.2	203	182	8.0	6.58	2.29	46,200	62

Table XXII.—Summary of analyses, downstream stations: Discharge 0.432-1.234 and 1.235 and above c. f. s. per square mile. Arithmetic average—Continued

Station temperature range °C.	Number of samples	Discharge c. f. s. per square mile	Temperature °C.	Suspended solids p. p. m.	Alkalinity p. p. m.	pH	D. O. p. p. m.	5-day B. O. D. p. p. m.	Bacteria/ml.	
									37° C. count	Coliform
DISCHARGE 1.235 AND ABOVE C. F. S. PER SQ. MILE										
Chillicothe:										
9.9 and below.....	22	3.27	4.8	377	132	7.6	11.41	3.75	22,600	894
10-19.9.....	13	2.99	13.5	341	142	7.7	8.55	3.94	26,300	452
20 and over.....	14	3.30	23.8	486	131	7.6	4.59	3.60	191,000	569
Kilgore:										
9.9 and below.....	19	3.55	5.0	394	133	7.6	11.36	3.76	29,000	450
10-19.9.....	13	2.87	13.2	317	146	7.7	8.63	3.42	31,200	457
20 and over.....	13	3.30	23.9	478	133	7.7	4.75	3.59	142,000	520
Higby:										
9.9 and below.....	18	3.01	4.8	459	139	7.7	11.44	3.63	30,900	502
10-19.9.....	15	3.83	12.8	429	143	7.6	8.84	3.41	33,700	481
20 and over.....	11	2.98	23.7	517	125	7.7	4.78	3.32	166,000	492
Waverly:										
9.9 and below.....	22	2.76	4.5	413	132	7.6	11.37	3.18	20,700	309
10-19.9.....	14	3.38	13.0	488	139	7.7	8.75	3.62	23,800	222
20 and over.....	11	2.98	23.9	630	120	7.7	4.72	3.23	159,000	452
Lucysville:										
9.9 and below.....	24	2.92	4.9	468	128	7.6	11.25	2.60	30,600	217
10-19.9.....	12	3.15	13.6	315	139	7.7	8.41	2.72	15,700	129
20 and over.....	11	2.97	24.0	797	139	7.7	4.80	3.03	166,400	309

TEMPERATURES

The temperature groupings used in summarizing the results of this survey follow roughly those used in previous studies of the Ohio and Illinois Rivers, although in these previous surveys the results were summarized by months and were separated into winter, summer, and transitional periods.

This is illustrated in figure 16 which is a plot of the daily variation in river water temperatures at Shadeville (13) during the period of the survey showing their distribution throughout the calendar year. There are also shown on the chart the temperature groupings obtained by using seasonal divisions as on the Ohio and Illinois River surveys.

The river temperatures shown on this chart were read as a rule fairly early in the morning, usually about 9:00 a. m., especially during the summer months. They probably represent approximately the minimum temperatures of a diurnal variation which is small in winter but amounts to several degrees during summer and fall low flows as shown by an intensive 24-hour sampling carried out at Chillicothe (61) on July 25, 1939. This sampling gave a variation of 4.5° C. from 22.5° C. at 6 and 7 a. m. to 27° C. at 6:00 p. m.

River temperatures on the Scioto, as might be expected in a small stream, follow rather closely a running average of the mean daily air temperatures of the several preceding days. Figure 17 shows river temperatures throughout the year 1938 at Shadeville, 13 river miles

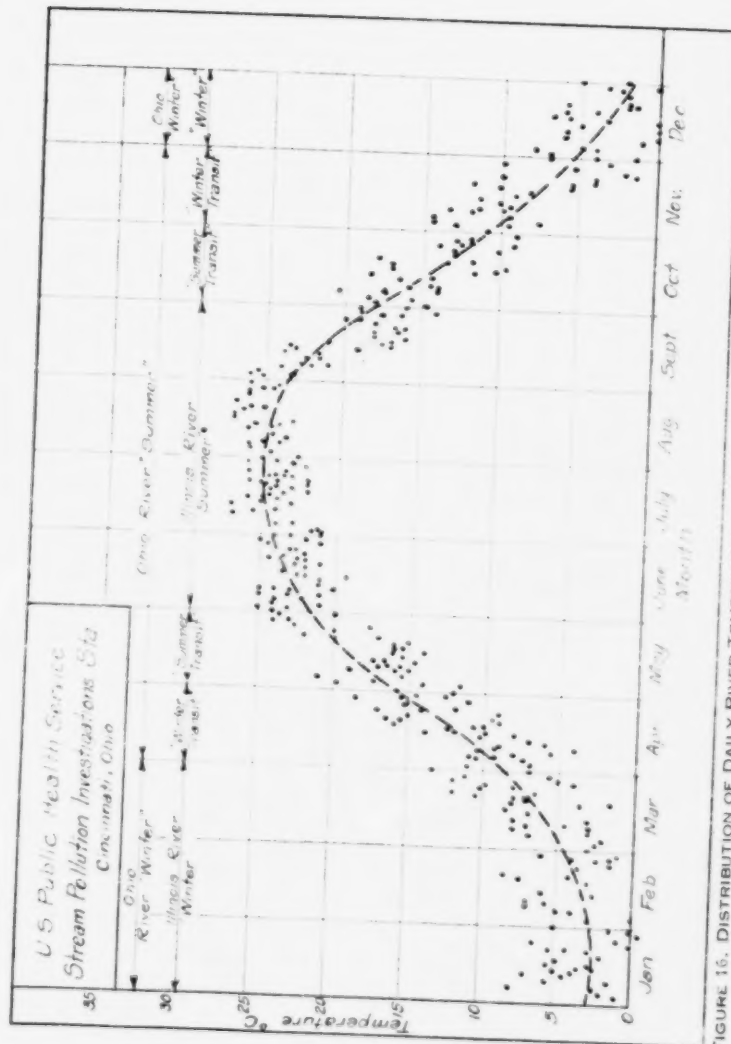


FIGURE 16. DISTRIBUTION OF DAILY RIVER TEMPERATURES AT SHADEVILLE (13). COMPARISON WITH TEMPERATURE GROUPINGS USED ON PREVIOUS SURVEYS OF THE OHIO AND ILLINOIS RIVERS.

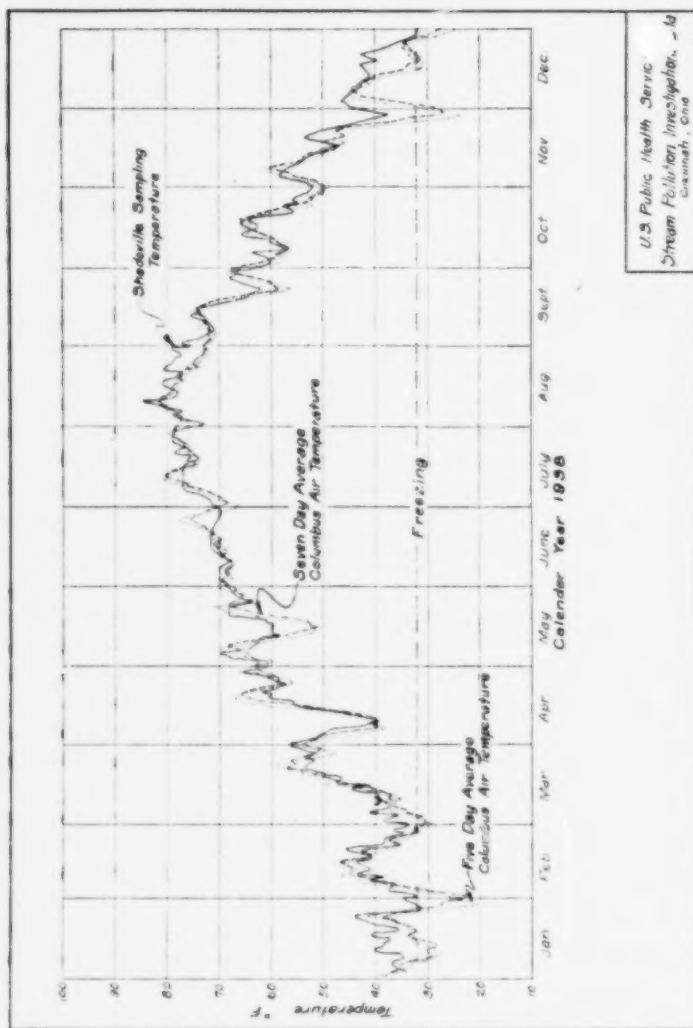


FIGURE 17. COMPARISON OF DAILY RIVER TEMPERATURES AT SHADEVILLE WITH RUNNING AVERAGES OF THE PRECEDING 5 AND 7 DAY MEAN AIR TEMPERATURES AT COLUMBUS.

south of Columbus, plotted together with the running average of the preceding 5 and 7 days Columbus, Ohio, mean air temperature as reported by the U. S. Weather Bureau. It will be noted that the greatest deviations occur when the running averages of the mean daily air temperatures drop below freezing, 32° F. Otherwise the correspondence between river temperatures and either the 5 or 7 day running average is generally quite good, especially in view of the large diurnal variations which must occur at times. Eriksen and Townsend (11) have reported upon a similar study of harbor water temperatures where the water temperatures were consistently higher than the 3 and 7 day mean air temperatures and cited prior work by Miller, Ramage and Lazier (12) who found water temperatures in San Francisco Bay to be consistently higher than air temperatures. These latter investigators attributed their findings to intense solar radiation upon extensive isolated shoal areas. Some such effect would probably be indicated in the Scioto had mean water temperatures been used instead of temperatures taken during the early forenoon. In this connection, the two periods during warm weather when water temperatures exceeded mean air temperatures by 6°-8° F. occurred in mid-May and late August and both occurrences were preceded by constantly dropping river stages, which reached new low stages for the season.

BACTERIOLOGICAL RESULTS

The summation of the analyses of river-water samples grouped according to temperature and discharge per square mile gives a series of pictures of pollution in the river under these various conditions. Omitting the lowest discharge range (0.00-0.077 c. f. s. per square mile) because of the paucity of observation, and the highest discharge range because of the inclusion of flood flows, there are nine complete sets of averages of river conditions with three discharge ranges in each of three temperature groups.

In figures 18-21 inclusive, plots are shown of the changes occurring, expressed in average quantity units¹, for four sets of conditions throughout the length of river studied. Although erratic, it will be observed that there is a general tendency for bacterial numbers to decrease at a linear rate when plotted on semilogarithmic paper against times of flow. In order to summarize these rates with varying temperatures, least square fittings (13) of the logarithms of the quantity units of coliform bacteria and of 37° C. counts plotted against times of flow have been made for the four stations, Shadeville, Commercial Point, South Bloomfield, and Red Bridge. The slope of the line best fitting the logarithms of the quantity units of bacteria when plotted against times of flow would define a constant *k* in the formula

¹ 1 quantity unit (q. u.) = Bacteria per ml. × thousands of c. f. s. discharge.

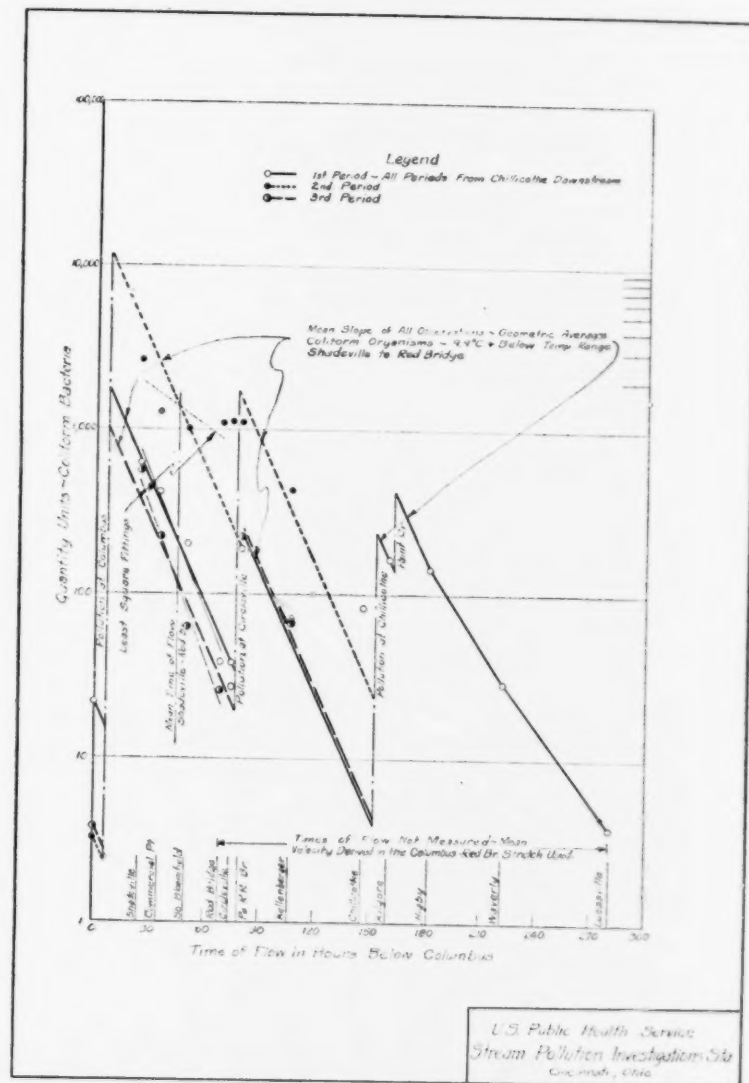


FIGURE 19. PROFILE SHOWING THE RATES OF DECREASE OF THE GEOMETRIC AVERAGES OF COLIFORM BACTERIA AT 9.9 C. AND BELOW IN THE .078-.216 C. F. S. PER SQUARE MILE DISCHARGE RANGE.

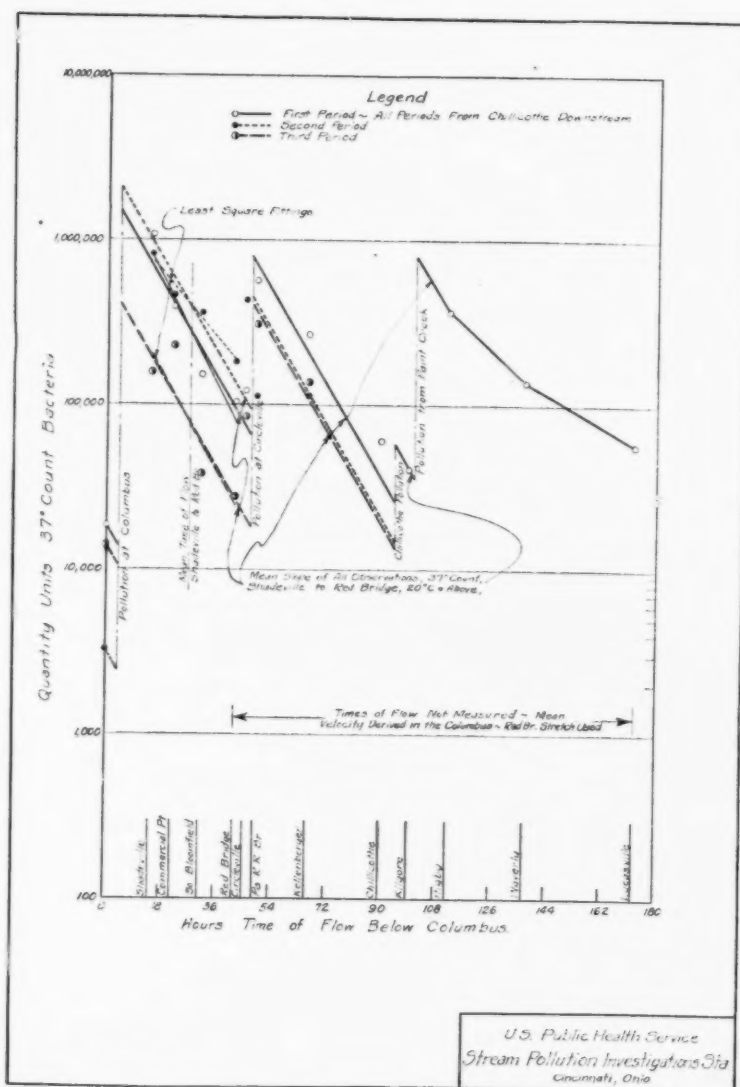


FIGURE 20. PROFILE SHOWING THE RATES OF DECREASE OF THE ARITHMETIC AVERAGES OF 37° C. COUNT BACTERIA AT 20° C. AND ABOVE IN THE .217-.431 C. F. S. PER SQUARE MILE DISCHARGE RANGE.

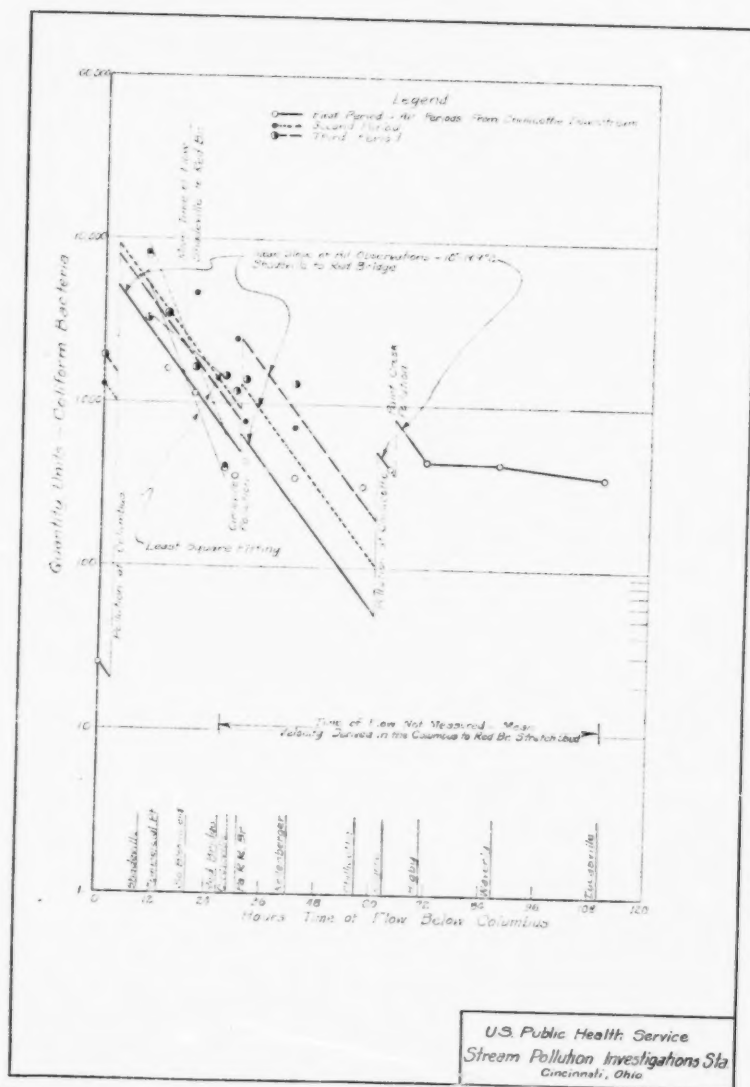


FIGURE 21. PROFILE SHOWING THE RATES OF DECREASE OF THE ARITHMETIC AVERAGES OF COLIFORM BACTERIA AT 10°-19.9° C. IN THE .432-1.234 C. F. S. PER SQUARE MILE DISCHARGE RANGE.

$y = b 10^{kt}$, where y = the quantity units of bacteria present, t = the time of flow in days, and b = quantity units of bacteria present at zero time. These constants are given in table XXIII, for the arith-

Table XXIII.— k values defining the rates of bacterial decrease for the stretch, Shadeville to Red Bridge

Discharge range c. f. s./sq. mi.	9.9° C. and below			10°-19.9° C.			20° C. and above		
ARITHMETIC AVERAGE QUANTITY UNITS OF COLIFORM									
	1st period	2d period	3d period	1st period	2d period	3d period	1st period	2d period	3d period
0.078 to 0.216.....	+0.044	+0.074	-0.683	-0.652	-0.460	-1.014	-1.23	-1.144	-0.492
0.217 to 0.431.....	-739	-923	-532	-1.126	-595	-389	-1.30	-1.014	-770
0.432 to 1.234.....	-506	-388	-552	-1.62	-1.585	-560	-709	-1.614	-345
Mean.....	-0.467			-0.889			-0.957		
ARITHMETIC AVERAGE QUANTITY UNITS OF 37° C. PLATE COUNTS									
0.078 to 0.216.....	-0.318	-0.129	-0.664	-0.665	-0.406	-0.715	-0.885	-0.692	-0.710
0.217 to 0.431.....	-355	-711	-401	-387	-706	+043	-887	-540	-807
0.432 to 1.234.....	+064	-151	-174	-875	-1.612	-144	-627	-1.350	-293
Mean.....	-0.316			-0.607			-0.755		
GEOMETRIC AVERAGE COLIFORMS IN QUANTITY UNITS									
0.078 to 0.216.....	-0.662	-0.191	-0.733	-1.09	-0.660	-0.802	-1.08	-1.05	-0.326
0.217 to 0.431.....	-662	-1.07	-478	-897	-743	-658	-814	-976	-760
0.432 to 1.234.....	-617	-347	-576	-1.45	-1.77	-752	-820	-1.27	-617
Mean.....	-0.593			-0.980			-0.858		

metic averages of the quantity units of coliform bacteria and 37°C. counts respectively and for the geometric averages of coliforms, also expressed in quantity units.

In figures 18 to 21 the least square fittings of the observations between Shadeville and Red Bridge are plotted and the averages of the various k values obtained for each temperature range are fitted to the observations as noted on each of the charts.

Between Circleville and Higby these same k values are used and are fitted, visually, to the observed results. Below Higby, the observed values are connected by a series of straight lines.

The only times of flow computed from field measurements are those for the stretch between Columbus and Red Bridge. Below Red Bridge, the times of flow used were obtained by assuming that the mean velocity obtained in the Columbus and Red Bridge stretch would hold constant throughout the stream for a given unit discharge per square mile. In general, this probably holds true for the lowest discharge range, 0.078-0.216 c. f. s. per square mile, as in this range

the rate of decrease of bacteria appears to be about the same downstream as it is in the upper reaches where times of flow were computed. The two higher discharge ranges, 0.217 to 0.431 and 0.432 to 1.234 however, show progressively a much lower rate of decrease of bacteria below Higby than was observed in the upper reaches when using velocities derived from Shadeville to Red Bridge for a given discharge range, a fact which could be partially accounted for by higher velocities in the lower reaches of the river in the same discharge range. In the highest discharge range (fig. 21), however, decreases below Higby were quite small and some factor such as intermediate increments of pollution, a more or less uniform loading, is indicated.

Lower rates of decrease in both bacteria and B. O. D., as the distance from an intense source of pollution increases, have been consistently reported in the literature and are a well established fact. The causes of such decreases are not completely understood but recent work in the field of sewage purification has stressed the high rates of purification obtained with activated sludge where an intense concentration of bacteria working in a favorable environment provides extremely rapid purification. A series of measurements made in the stretch of the Scioto between Columbus and Shadeville during the third period gave extremely rapid rates of B. O. D. removal and the average rates of decrease for both bacteria and B. O. D. in this stretch are probably greater than in the stretch from Shadeville down to Red Bridge. The decreasing rates of purification observed below Higby, at higher discharges, however, presents a different picture than that which would be obtained with a decreasing rate which was due to a lower biological content in the stream. It, therefore, seems probable that something in the nature of a uniform loading must be responsible for the lower rates of decrease observed at higher river stages. Such a uniform loading could conceivably be derived from either pick up of organic matter from the stream bed due to higher stream velocities, or to material washed into the river by the rains which were a necessary accompaniment of the higher discharges.

The geometric averages of coliform bacteria as shown in figure 19 were computed in order to lessen the effect of occasional high concentrations of bacteria which tend to make the arithmetic average appear erratic. Figures 18 and 19 are the arithmetic and geometric averages respectively of the same base data. Comparison of these figures indicates that the geometric average tends to be lower and somewhat less variable than the arithmetic averages. The average k values obtained by these two methods of averaging as shown in table XXIII do not differ greatly and the differences obtained are quite probably within the limits of variation of the base data.

The increments of pollution at Columbus, Circleville, Chillicothe, and Paint Creek are shown in figures 18 to 21 as immediate increases

to a point which corresponds to a backward extrapolation of the average rate of decrease. In an analysis of the Ohio River bacterial curves, Streeter (14) has shown that the maximum concentration of bacteria occurs some distance below the point of pollution, so that the extrapolated maximum concentration as indicated at the point of pollution on these figures is probably never reached. This is illustrated by figure 18, where the results of eight sets of samples taken at intermediate points between Circleville and Chillicothe during the month of December 1938, a period of relatively constant low water, are plotted. This series shows a maximum occurring at sampling station Mile 37, approximately 4 river miles below the point of pollution, but in general checks quite well with the average observations during the third period in this stretch of the river. The purpose of this intensive sampling was to check discrepancies observed in the Chillicothe sampling station (61). This and later studies have indicated that the Chillicothe (61) sampling station gave consistently high values for B. O. D. and bacteria largely because of the unsuspected discharge of a small amount of slaughterhouse waste above this sampling point during the period when samples were ordinarily taken.

Corrections for tributary inflow.—When calculations of bacterial content are based on total quantities, such as "quantity units," corrections applied for tributary inflow must also be based on the total quantities contributed to the stream by the tributary. In the upper part of the Scioto, the pollution is so heavy that tributary corrections run much less than 1 percent for the bacteriological data. A plot of the data from tributaries indicates that the corrections for coliform bacteria in discharge ranges below 0.5 c. f. s. per square mile for Big Walnut, Darby, and Deer Creeks would be less than one quantity unit. Above 0.5 c. f. s. per square mile discharge, the correction increases rapidly amounting, at 1 c. f. s. per square mile, to approximately 18 quantity units for coliform bacteria for Big Walnut Creek, 12 quantity units for Darby Creek, and 10 for Deer Creek. On account of shortened times of flow in the Scioto at these higher discharge ranges, however, bacterial decreases were much less, resulting in higher quantities of bacteria being carried by the stream at downstream stations. Thus, although tributary corrections were much higher than at lower discharge ranges, they were still negligible and it was not necessary to apply corrections for these inflows.

Comparison of bacterial changes with those of previous surveys.—In figure 22 comparative rates of decrease for coliform bacteria and for the 37° C. plate counts for the Ohio, upper Illinois, and Scioto Rivers are given. Plotted on semilog paper, these show the decreases

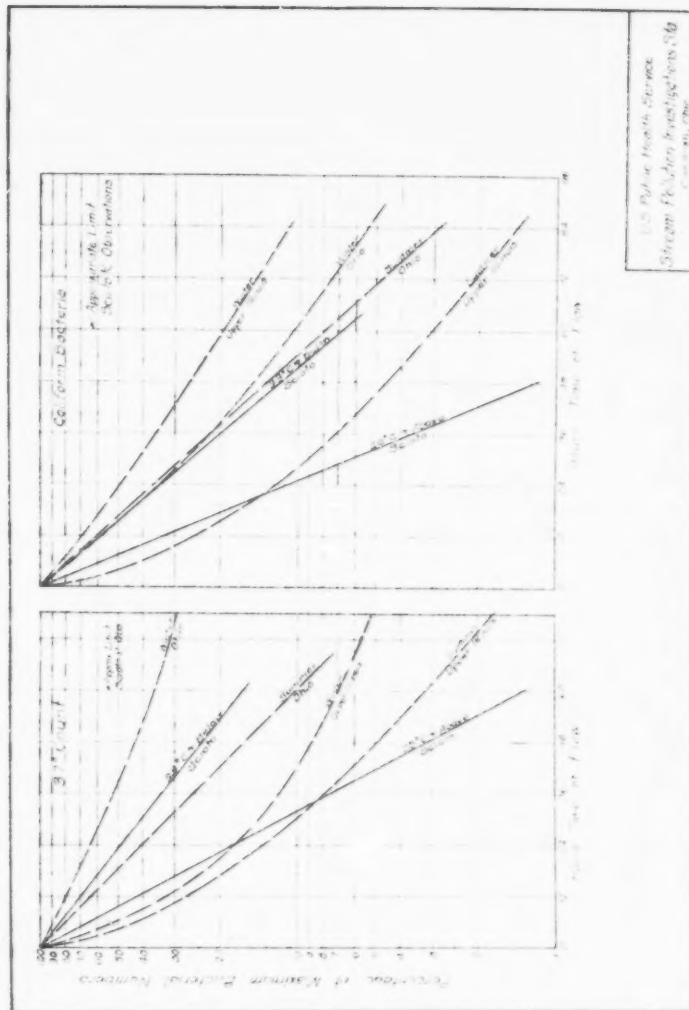


FIGURE 22. RATES OF DECREASE OF BACTERIA IN THE SCIOTO RIVER BETWEEN SHADEVILLE AND RED BRIDGE COMPARED WITH THOSE IN THE OHIO AND ILLINOIS RIVERS.

in the Scioto to be linear for 60 hours, the approximate limit of measurement on the upper Scioto.

Based on a study of the 37°C. plate counts, the rates of bacterial decrease in the upper Illinois River during the first few hours were higher in both the summer and winter periods than those observed in the Scioto River, even when comparable summer rates in the Scioto were considered. However, in the upper Illinois both the summer and the winter rates of bacterial decrease slackened after the first few hours and after about 40 hours they were less than the winter rate in the Scioto. There was also considerably less divergence between winter and summer rates of decrease on the upper Illinois than there was between comparable rates on the Scioto. Rates of decrease shown by 37°C. counts on the Ohio were nearly linear on semilog paper within the 60-hour period during which comparisons can be made and the divergence between summer and winter rates was approximately that found in the Scioto, both winter and summer rates in the Ohio being very roughly about half those observed in the Scioto.

Based on a study of coliform bacteria the rates of decrease in the Ohio River when plotted on semilog paper were approximately the same, both winter and summer, as the winter rate in the Scioto. In the upper Illinois, the summer rate was greater than that in the Scioto during the first few hours, but decreased rapidly and was much less after 30 hours than that in the Scioto. The winter rates of decrease of coliform bacteria in the upper Illinois were more nearly linear than summer rates in the same stream but were considerably lower than the winter rates observed in the Scioto.

RESULTS OF CHEMICAL ANALYSES

The average results of chemical analyses are given in tables VI-XXII, along with bacteriological and other data, it being more convenient to express the results in this form than to present separate tables for the different sections. The techniques of the various tests made on individual samples; pH, alkalinity, suspended solids, dissolved oxygen and biochemical oxygen demand are discussed in the section on sampling methods and laboratory technique. Discussion in this section will therefore be limited largely to variations in the means of the determinations made with changes in other factors such as pollution and physical conditions.

In addition to the above mentioned chemical analyses, monthly composites of the daily samples were made at several stations and analyzed in the Cincinnati laboratory for ammonia, nitrites, nitrates, and organic nitrogen. The results of these analyses are reported in appendix I.

Hydrogen ion concentration.—The pH of the Scioto varied generally between 7.5 and 8.0. At Columbus (3) the pH averaged about 8.0 at low and intermediate stages. This dropped to about 7.5 following the addition of Columbus sewage after which the pH rose slowly throughout the length of river studied until at the lowest station, Lucasville (115) the pH averaged about the same as at Columbus (3). At highest stages, 1,235 c.f.s. per square mile and above, the pH varied little throughout the length of river studied, averaging about 7.6. A slight but consistent tendency was observed for the average pH to rise 0.1–0.2 at low stages with increasing temperatures, probably due to the increased algal activity occasionally producing normal carbonates in the stream. One of the tributaries, Salt Creek, had an average pH of about 7.2–7.3 but the other tributaries were slightly higher in pH than the main stream. The pH in the Scioto was always maintained well within the range of normal biological activity and consequently the pH variations which occurred are considered to be of little sanitary significance.

Alkalinity.—Alkalinities in the Scioto show little, if any, tendency to vary with temperature and only a very slight tendency to increase at the lower stations compared to the upper ones. There is a considerable decrease in alkalinity as river stages rise, however as can be seen in figure 23, a plot of alkalinities, at stations downstream from Chillicothe, against river discharges in c.f.s. per square mile. The plotted points represent station averages of all observations within a certain temperature and discharge range. At lowest stages, the mean of these plotted points is an alkalinity of about 240 p.p.m. with roughly 20 p.p.m. deviation from the mean. At highest stages, the mean of the plotted points is about 130 p.p.m. alkalinity with somewhat less deviation from the mean than occurred at low stages. Tributary alkalinities were generally about the same as those in the main stream except for Salt Creek where alkalinities usually ran about one-third those of the Scioto itself.

Alkalinities, being basically a measure of a water's resistance to the effect of acids, have little sanitary significance unless pollution by acid is involved, or unless concurrent studies are being made of stream forms requiring large amounts of calcium for their life processes. Carbonate alkalinities may be useful as an indicator of intense activity of photosynthetic organisms, which may produce such alkalinity by abstracting carbon dioxide from bicarbonates. It seems doubtful, however, if the routine determination of alkalinities for stream pollution surveys is justified.

Suspended solids.—The suspended solids content of Scioto River water varied greatly at each sampling station. The average of large numbers of observations indicates a trend which is roughly linear when suspended solids are plotted against river discharges as can be

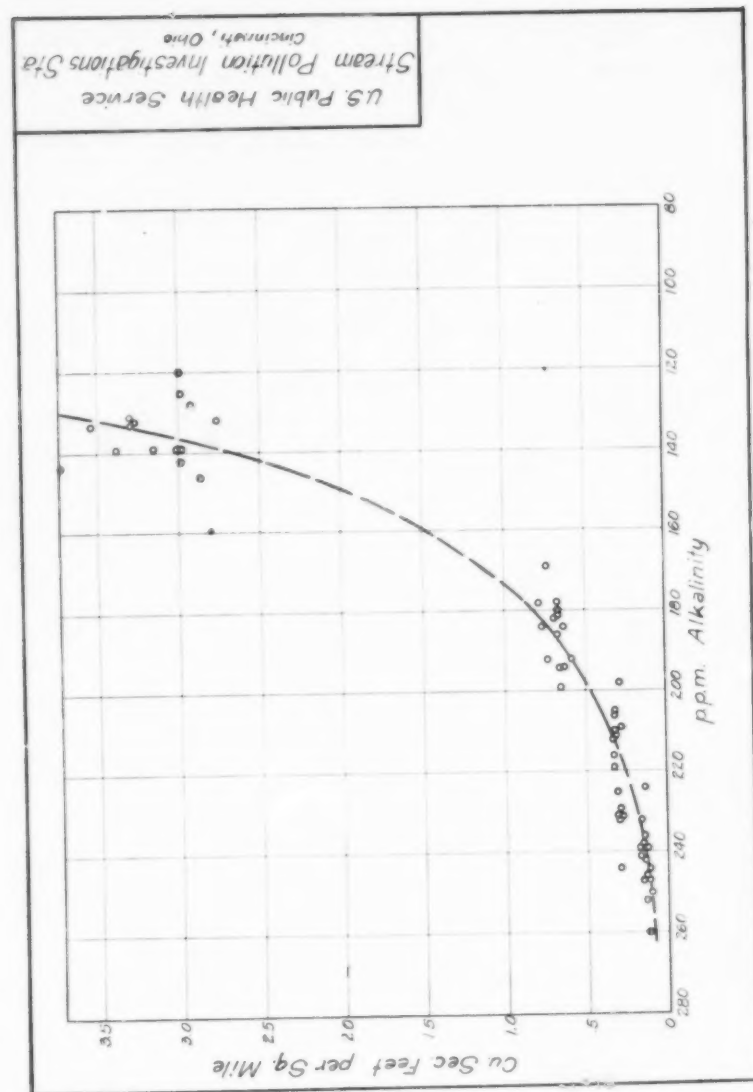


FIGURE 23. RELATION BETWEEN ALKALINITY AND FLOW IN THE SCIOTO RIVER BELOW CHILLICOTHE.

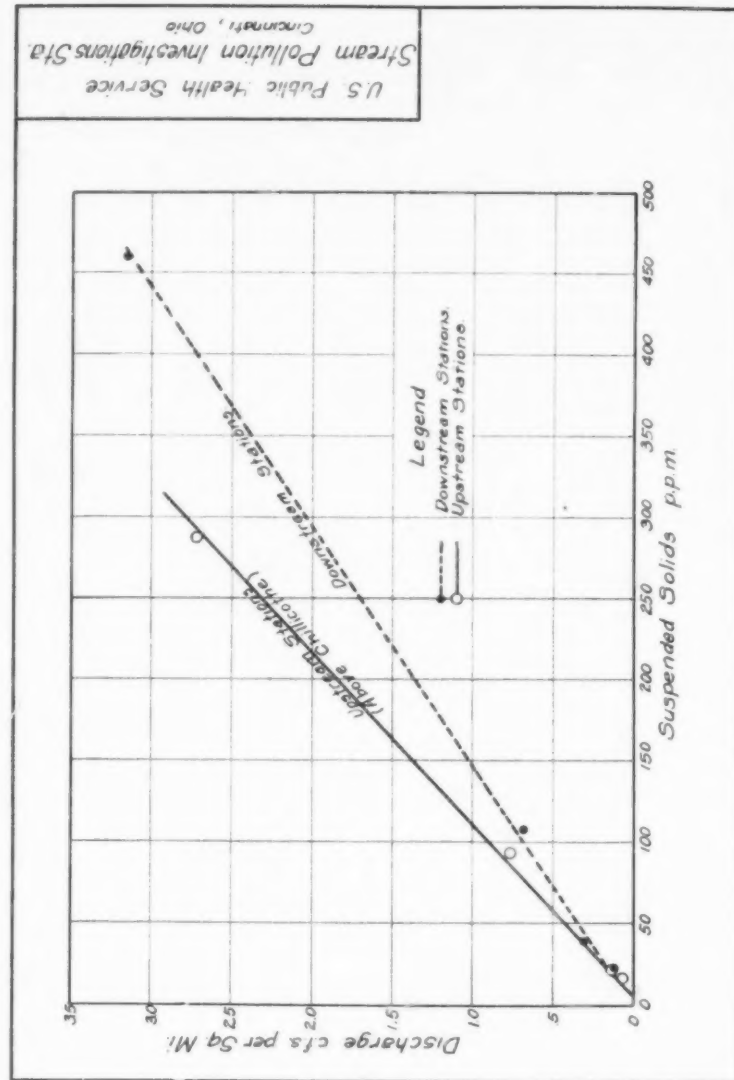


FIGURE 24. RELATION BETWEEN SUSPENDED SOLIDS AND FLOW IN THE SCIOTO RIVER.

seen in figure 24. In figure 24 are included all observations made during the survey, separated into upper and lower river stations and grouped according to discharge range. At low river stages there is no significant difference in the average values for suspended solids, but at higher stages the upstream stations average about 75 percent of the suspended solids content of the downstream stations.

BIOCHEMICAL OXYGEN DEMAND

The oxygen demand of the flowing water of a stream, as measured by the biochemical oxygen demand test (B. O. D.), has been exhaustively studied by Streeter (15) in his excellent report upon this subject. The practical application of this test in following, quantitatively, the changes occurring in a polluted stream is modified by a number of factors which Streeter (15) lists as (1) intermediate inflow, (2) sedimentation and absorption, (3) channel scouring, (4) "immediate" or "enzymic" oxygen demand and (5) a transition from first (carbonaceous) to second (nitrogenous) stage oxidation in the stream proper.

In this present study of the Scioto, an effort has been made to follow, quantitatively, the changes occurring in the total B. O. D. carried by the stream at various river stages and temperatures. This was done by computing the total amount of 5-day B. O. D. in the river from the station averages of discharge and 5-day B. O. D. and, in some cases, by computing the total oxygen demand in the river by applying factors to the 5-day biochemical oxygen demand test to obtain an estimated total oxygen demand. In addition to the factors which Streeter (15) mentioned, such calculations in the present study were complicated by the absence of routine determinations in the stretch of river between Columbus and Shadeville, the 8-mile stretch of river immediately below the Columbus sewer outlet. It is known that purification rates were high within this stretch of river, but the data available are insufficient to accurately estimate variations in purification rates under varying river conditions for this stretch.

A distinction should be made at this point between the rate of deoxygenation in bottles in the B. O. D. test and the rate of natural purification, as measured by B. O. D. reduction in streams. Streeter (15) has shown that the two may be approximately equal in the flowing water of some larger rivers with regard to first stage (carbonaceous) oxygen demand but that the second stage (nitrogenous) demand in these rivers may approximate one third of the normal rates of first stage oxidation in the B. O. D. test. It is, therefore, not to be expected that such purification rates in a river will necessarily follow the oxidation rates in the B. O. D. test.

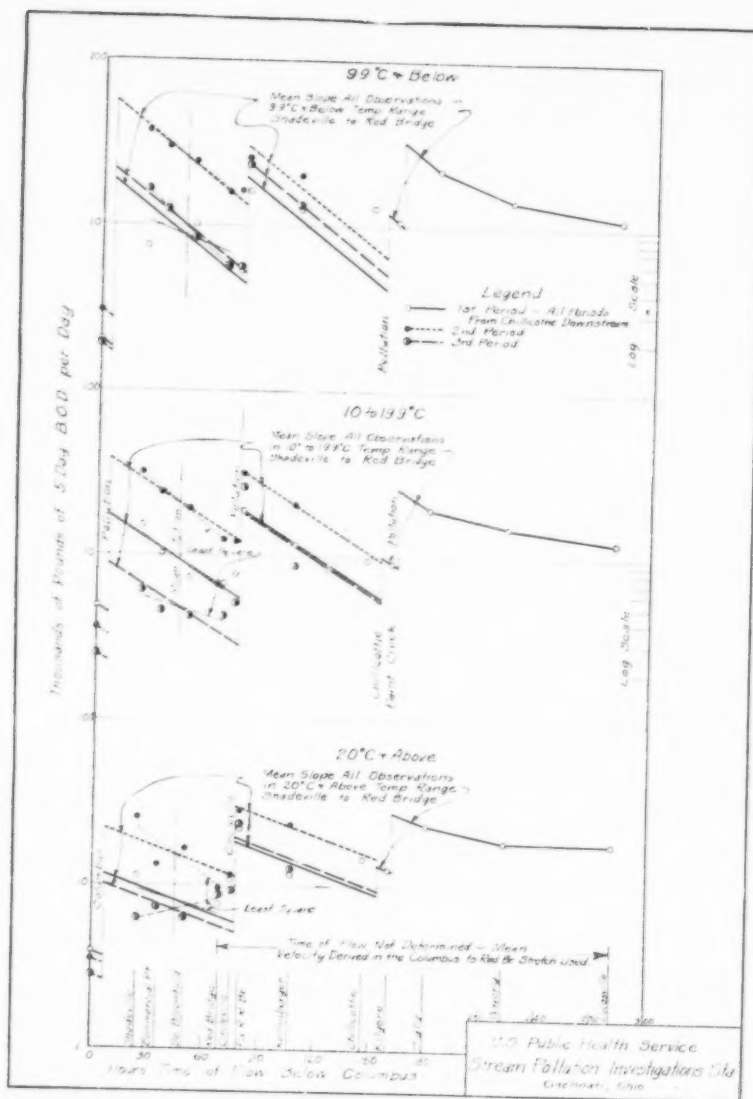


FIGURE 25. PLOT OF ARITHMETIC AVERAGES OF B. O. D. RESULTS IN THOUSANDS OF POUNDS OF 5-DAY B. O. D. PER DAY, INCLUDING ALL TEMPERATURE RANGES IN THE .078-.216 C. F. S. PER SQUARE MILE DISCHARGE RANGE.

The determination of rates of natural purification as measured by the biochemical oxygen demand test is based on the assumption that the rate of decrease in biochemical oxygen demand is proportional to the amount of remaining biochemical oxygen demand after time t or

$$\frac{dL}{dt} = -K^1 L$$

where L is the first stage (carbonaceous) oxygen demand left in the river after time t , in days, which integrated gives

$$L = L_0 e^{-K^1 t}$$

$$L = L_0 10^{-K^1 t} \text{ where } K^1 = 2.303 K$$

$L_0 = \text{initial B. O. D.}$

Plotted on semilogarithmic paper against time t on the linear scale, the total 5-day B. O. D. values observed in the river in thousands of pounds per day, corrected for inflow, should give a linear plot with the slope of the line defining " K ." Figure 25 shows such plots of the 5-day B. O. D. obtained in the discharge range 0.078-0.216 c. f. s. per square mile. Similarly, a plot of the logarithms of the computed L values would also give a linear rate of decrease with the slope of this line defining " K ." In order to obtain a direct comparison between the rates of decrease of B. O. D. in the Scioto at various temperatures and discharges, least square fittings have been made of the logarithms of the average B. O. D. figures for the four sampling stations Shadeville, Commercial Point, South Bloomfield, and Red Bridge, the only stretch of river for which time of flow data were available. The slopes of the lines thus derived are given in table XXIV. For comparative purposes a series of comparable " K " values have been computed in order that the effect of certain factors upon these " K " values may be more readily discussed.

Table XXIV.—Least squares determination of " K " values defining the rate of decrease of biochemical oxygen demand in the Scioto River—Shadeville to Red Bridge. Mean values for 3 periods of varying pollution

Conditions	0.078-0.216 c. f. s. per square mile			0.217-0.431 c. f. s. per square mile		
	9.9° C. and below	10-19.9° C.	20° C. and above	9.9° C. and below	10-19.9° C.	20° C. and above
(1) Arithmetic average, thousand lbs. per day—5-day B. O. D.	-0.178	-0.152	-0.063	-0.326	-0.010	-0.049
(2) Arithmetic average, thousand lbs. per day—5-day B. O. D., with " K " values weighted according to average number of samples	-.201	-.129	+.017	-.364	-.018	-.035
(3) Arithmetic average (1) corrected for tributary inflow	-.183	-.160	-.067	-.333	-.020	-.070
(4) Geometric average, thousand lbs. per day—5-day B. O. D.	-.205	-.220	-.155	-.454	-.172	-.235
(5) Total carbonaceous demand based on long-time B. O. D. tests, thousand lbs. per day	-.113	-.090	-.037	-.223	+.100	+.050

Table XXIV.—Least squares determination of "K" values defining the rate of decrease of biochemical oxygen demand in the Scioto River—Shadeville to Red Bridge. Mean values for 3 periods of varying pollution—Continued

Conditions	0.432-1.234 c. f. s. per square mile			Average		
	9.9° C. and below	10-19.9° C.	20° C. and above	9.9° C. and below	10-19.9° C.	20° C. and above
(1) Arithmetic average, thousand lbs. per day—5-day B. O. D.	-0.094	-0.202	-0.140	-0.199	-0.151	-0.084
(2) Arithmetic average, thousand lbs. per day—5-day B. O. D., with "K" values weighted according to average number of samples	-.092	-.323	-.126	-.219	-.157	-.048
(3) Arithmetic average (1) corrected for tributary inflow	-.113	-.327	-.170	-.210	-.169	-.102
(4) Geometric average, thousand lbs. per day—5-day B. O. D.	-.350	-.419	-.291	-.336	-.270	-.227
(5) Total carbonaceous demand based on long-time B. O. D. tests, thousand lbs. per day	+.057	-.147	+.010	-.063	-.046	+.007

All of the "K" values in table XXIV are based on thousands of pounds of B. O. D. per day thus making the corrections for inflowing B. O. D. between stations a matter of adding in the tributary contributions in thousands of pounds per day. Each of the "K" values in this table is the average of 3 values, from the three periods of varying pollution at Columbus.

In the first horizontal line of figures in table XXIV are shown the "K" values determined for the arithmetic averages, by temperature and discharge ranges, of the total 5-day B. O. D. in this stretch of river. The last three figures in each of the horizontal lines are the average values of the three discharge ranges for the temperature shown.

Because of the relatively few sets of observations in some of the temperature and discharge groups, weighted averages were computed for the individual "K" values based on the assumption that the more observations in each group, the more accurate would be the final "K" value. These weighted averages of "K" values derived from the arithmetic average of 5-day B. O. D. at each station, are given in the second horizontal line in table XXIV. It will be observed that, while fairly large deviations occur between comparative "K" values, the net result is a slight increase in the temperature effect as shown in the last three figures on this line.

Corrections for inflowing B. O. D., made only in the Shadeville and Red Bridge stretch, were small as can be seen by referring to the third line of table XXIV. The net effect of such corrections is a slight uniform increase in all "K" values in line 3 compared to line 1. Tributary corrections were made by deducting from stations below tributaries, the estimated residual B. O. D. of that contributed, applying the normal rates of decrease of B. O. D. in bottles for the given temperature and time of flow.

Because of the presence of occasional "slugs" of pollution as indicated by individual B. O. D. values greatly in excess of the average, it was thought desirable to determine the effect of such "slugs" of pollution by using geometric averages of the individual analyses at each station instead of arithmetic averages as the former would tend to minimize the effects of such occasional high figures on the averages. The "*K*" values derived from these geometric averages are shown in horizontal line 4 of table XXIV. In general, the "*K*" values thus determined are higher than those in line 1 indicating the greater frequency of unusually high values at the lower stations. The temperature effect, although lessened, still retains its downward trend with increasing temperatures.

INVERSE CORRELATION OF TEMPERATURE AND B. O. D. REDUCTION

The temperature effect as can be noted in all of these calculations is perhaps the most striking factor to be observed in table XXIV. Its meaning is quite clear, i. e., under the various methods of calculation employed, in the particular stretch of Scioto River used and as measured by 5-day results of the biochemical oxygen demand test, an extensive series of observations indicate that the B. O. D. decreases more rapidly at low temperatures than at higher ones. The same tendency is indicated between Higby and Lucasville as shown in figure 25. This temperature effect observed is in contrast to the bacteriological results on the same stretch and to the usually observed effect of greater purification at higher temperature. The responsible factors seem logically to fall into three classifications, (1) progressive second stage oxidation in the B. O. D. test, (2) sedimentation and (3) other possibilities.

(1) *Progressive second stage oxidation in the B. O. D. test.*—One of the most troublesome factors in application of the B. O. D. test has always been the progressive oxidation of nitrogen from ammonia to nitrate. This tends to give a secondary rise in the curve of oxidation and the time and conditions under which this rise occurs are not completely understood. Any tendency to include a greater percentage of nitrogenous oxidation in the 5-day B. O. D. determination at lower stations over that in the B. O. D. test at higher stations during warm weather as compared to a decrease or absence of such effect at these lower stations during cold weather would tend to reverse the normal temperature effect of increasing purification rates with increasing temperatures.

Recent work by Butterfield, Ruchhoft and McNamee (16) and later work by Butterfield and Wattie (17) have shown that rates of oxidation are dependent upon the numbers and character of bacteria present, and the food supply as well as temperature. With this in mind a comparative set of "*K*" values is included in table XXIV,

horizontal line 5, based on a calculation of the total biochemical oxygen demand using factors derived from 25 day B. O. D. tests made daily on a single sample from each of the river stations in rotation. It will be observed that the "*K*" values for decrease in river B. O. D. in table XXIV, line 5, based on the long time B. O. D. tests are very much less than other comparable values in the same table, although still retaining a tendency for purification rates to be highest in the winter. These calculations of "*K*" values in the river based on long time B. O. D. tests, however, do indicate the tremendous effect of assumptions as to the ratio of 5-day B. O. D. to total B. O. D. in bottles on the derived rates of natural purification based upon the 5-day B. O. D. test.

In the determination of factors to be applied to the 5-day B. O. D. to get the estimated total first stage B. O. D. in parts per million of a given sample, a formulation of the deoxygenation curve of the sample similar to that used in the analysis of rates of decrease of B. O. D. in the river has been used. If *y* be taken as the B. O. D. of the sample during time *t*, *L* the ultimate B. O. D., *k*¹ the reaction velocity constant, then

$$y = L(1 - 10^{-kt}) \text{ where } k = .4343 k^1$$

Values of *k* (the deoxygenation constant) obtained from Scioto River samples at the four sampling stations directly below Columbus are presented in table XXV. As the number of observations involved

Table XXV.—Values of *k* for river water samples at four stations as derived from long time B. O. D. determinations

	Shadeville	Commercial Point	South Bloomfield	Red Ridge
1st period:				
January-April 1937.....	0.143	0.1005	0.0913	0.0978
May-August 1937.....	.0473	.0682	.0685	.0344
September-November 1937.....	.1155	.1520	.0348	.0515
Mean (weighted).....	.0913	.0972	.0557	.0574
2d period:				
December 1937-April 1938.....	.138	.1488	.1259	.0714
May-July 1938.....	.139	.0406	.0651	.0364
Mean (weighted).....	.139	.1041	.1077	.0603
3d period:				
August-December 1938.....	.0432	.0222	.0301	.0443
January-April 1939.....	.0892	.1036	.1002	.0688
May-August 1939.....	.0742	.0812	.0353	.0375
Mean (weighted).....	.0654	.0544	.0570	.0522

was large some method of compositing seemed advisable. Accordingly the samples were grouped as nearly as possible into seasonal periods. This roughly divides them into temperature classifications though it should be remembered that all samples were incubated at 20° C. throughout. That compositing of data is feasible is illustrated in figure 26. Four individual sets of data are evaluated for *k*. The

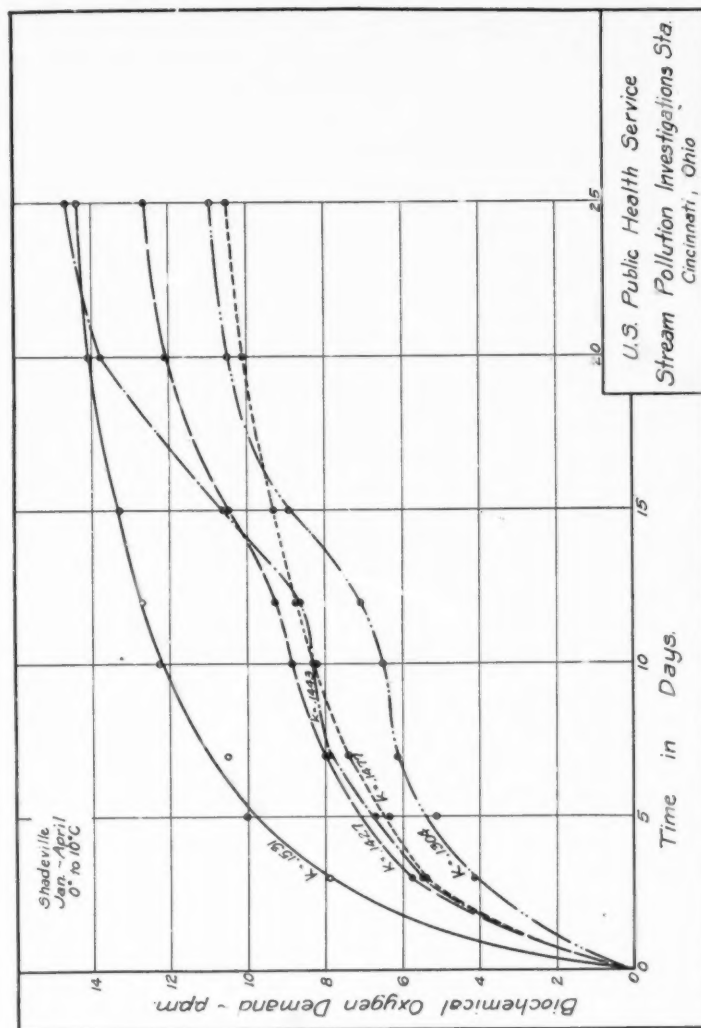


FIGURE 26. ILLUSTRATION OF METHOD OF COMPOSITING LONG-TIME B. O. D. RESULTS TO OBTAIN DEOXY-GENATION CONSTANTS.

mean of these is then found to be .1439. When the data are averaged beforehand a k value of .1427 is obtained for the composite data. The constant k was determined by the Thomas slope-method (18). To simplify the calculations the data, observed at unequal time intervals, were plotted and data at one day intervals obtained by interpolation. In general, data up to and including the 11th day were used in computing k . When a second or nitrification stage obviously occurred before the 11th day the number of observations used was reduced to eliminate this factor as much as possible. Such selection was not always possible as some data did not follow the form of the usually observed B. O. D. curve, with two distinct stages, but rather assumed the appearance of a second or nitrification stage immediately.

This phenomenon was most frequently observed in the fall of the year at higher temperatures and lower river stages. It was always accompanied by a sudden rise in nitrites in the river. It appeared more especially at South Bloomfield and Red Bridge. It is obviously difficult and possibly misleading to set arbitrary limits as to which data shall be included and which shall not, consequently, as it was felt that all data carried the same statistical weight, no figures were excluded. The effect of including these samples was to lower the deoxygenation constants on the long time oxygen demand tests. When factors derived from these long time tests are used to determine total B. O. D. in the river, the rates of decrease of B. O. D. in the river are very much lower as is clearly shown in line 5 of table XXIV.

An inspection of k values in table XXV reveals some definite trends. The second (plain sedimentation) periods shows the highest k values, the first (trickling filter) is lower and the third period (activated sludge) is lowest of all. On the average, k values are lower during the seasonal periods when the temperatures are highest. There is also a definite indication that k values decrease at the downstream stations. This suggests that these lower k values are due to the purification having been carried into the nitrification stage during these periods. The inclusion of a progressively greater proportion of nitrogenous oxidation in the 5-day B. O. D. test at downstream stations would tend to decrease the derived purification rates during warm weather and low flows. This effect undoubtedly contributes to the inverse correlation between temperature and purification.

On the whole, the evidence indicates that nitrification in bottles during the 5-day B. O. D. test and also probably some variation in the rate of oxidation of carbonaceous material made it very difficult to estimate accurately, or follow closely, the total B. O. D. carried by the Scioto.

(2) *Sedimentation*.—Sedimentation would, in general, be expected to increase the " K " values in table XXIV with increasing temperature, an effect opposite to that found. However, the uppermost

station, Shadeville, of those in the section of river under consideration, Shadeville to Red Bridge, was eight river miles below the point of pollution and a great deal of purification was accomplished in this eight mile stretch immediately above Shadeville especially in warm weather. It is, therefore, possible that sedimentation in the winter months was retarded and more occurred in the river below Shadeville than occurred in this stretch during warmer weather because of the more rapid settling and purification which had taken place above Shadeville during the warm months. Two sets of observations were made in this section between Columbus and Shadeville which indicate very rapid rates of decrease of B. O. D. These are shown in table XXVI. The figure given for mile 5.4, the Columbus outfall, was estimated from the volume and B. O. D. of composited effluent which was diluted about 25 percent by flow in the river. The river at that time was receiving large quantities of waste activated sludge from the Columbus sewage treatment plant. The high purification between mile 5.4 and 6 was caused largely by sedimentation in a river pool into which the Columbus plant effluent discharged and in which the waste activated sludge settled rapidly.

Table XXVI.—*B. O. D. at stations between Columbus and Shadeville for two periods in November–December 1938*

1938	Temperature °C.	5-day B. O. D. p. p. m.				
		Mile (5.4) outfall	Mile 6	Mile 8	Mile 10	Shadeville (13)
Nov. 3-17.....	13	48.4 (est.)	11.42	6.09	3.46	3.40
Dec. 20-27.....	3			36.51	25.12	21.30

(3) *Other possibilities.*—During warm weather and low stream flows dissolved oxygen was frequently absent from Shadeville and as far down as the mouth of Big Walnut Creek, where the volume of diluting water from this tributary was usually sufficient to establish aerobic conditions. In contrast, during winter, oxygen was present much more frequently. It is difficult to estimate the extent to which anaerobic conditions retarded the actual purification rate in summer compared to that in winter but it seems likely that there was such an effect.

The effect of warm weather upon the rate of decomposition of sludge deposits which had formed during previous cold weather is also very difficult to estimate but it seems likely that this effect was minimized by high water in the late winter and spring which usually scoured out the river bed rather thoroughly.

Another possible effect about which little is known, quantitatively, is the production of B. O. D. photosynthetically by plankton. This would be evident in two ways: (a) the oxygen demand of these

organisms during the night and at other times when they were not producing oxygen as a byproduct of photosynthesis, and (b) the release of carbohydrates and other synthesized products upon the death of these organisms. Either of these sources might give an appreciable oxygen demand, derived in the river, which would be unaccounted for by ordinary methods of summarizing the total oxygen demand in a river. Its effect would probably be greater in the lower than in the upper part of the Shadeville to Red Bridge stretch and would be evidenced by lower derived rates of purification in this stretch during the period when photosynthetic plankton were most abundant, i. e., during periods of high temperature and low water. That plankton were most abundant at such times is shown by figure 36, which gives the volumetric distribution of phytoplankton at low stages in the Scioto.

DISSOLVED OXYGEN STUDIES

The dissolved oxygen content of the Scioto River under the variations of temperature, stream discharge and intensity of pollution at Columbus forms a nicely graduated series of oxygen sag curves which are shown in figures 27, 28, and 29. Only the lowest discharge range, below 0.077 c. f. s. per square mile, and the highest discharge range, above 1.235 c. f. s. per square mile are omitted from this series of curves. Although there is always some decrease in dissolved oxygen in the upper river, between Columbus and Circleville, it is small in amount at low temperatures and high river stages (0.432-1.234 c. f. s. per square mile). With progressively increasing temperatures and decreasing river discharges the percentage of oxygen sag below saturation values for atmospheric oxygen at those temperatures becomes progressively greater. At highest temperatures dissolved oxygen values become quite low at Shadeville regardless of river stages (below 1.234 c. f. s. per square mile) during the second period. Similarly, at lowest stages, 0.078 to 0.216 c. f. s. per square mile, oxygen depletions occur at Shadeville at all temperatures except the lowest temperature range, 9.9° C. and below. It can be safely stated that the point of minimum dissolved oxygen concentration always occurs above Shadeville, which is eight miles below the source of pollution at Columbus, during warm weather and low flows, even though observations in this stretch were quite limited. Higher discharges and lower temperatures move the point of minimum dissolved oxygen concentration downstream, probably below Shadeville, although insufficient data are available above Shadeville to establish this definitely. Midway between Shadeville and Commercial Point a tributary, Big Walnut Creek, provides a large volume of high oxygen-content diluting-water, necessitating a considerable correction to the unmodified oxygen sag curve. Below the point of entrance of Big

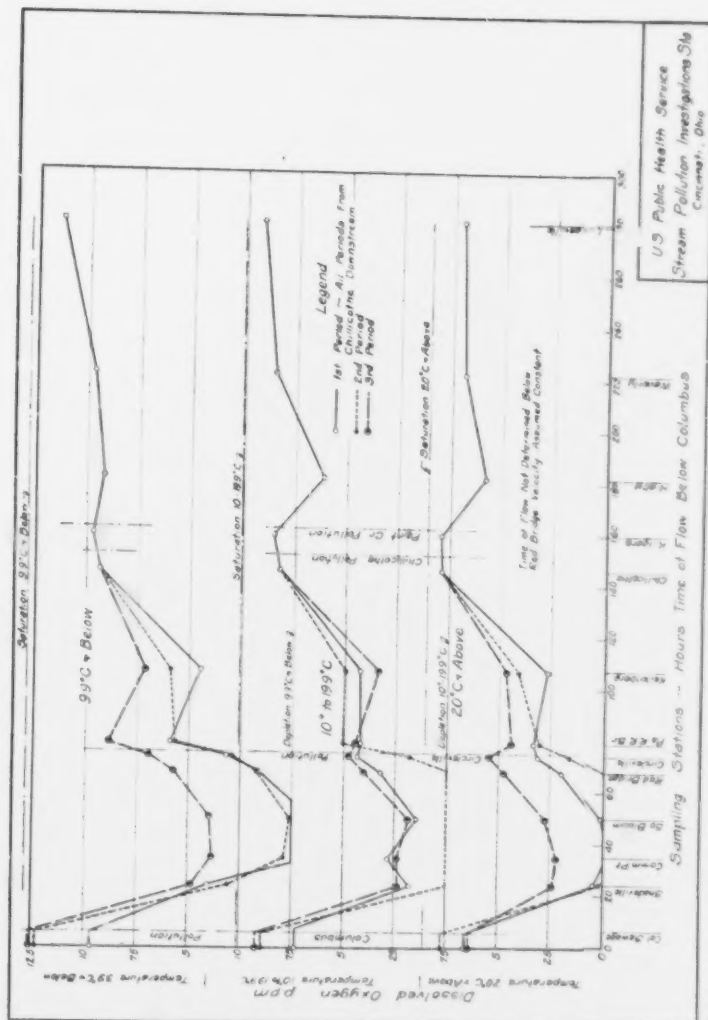


FIGURE 27. DISSOLVED OXYGEN PROFILES ON THE SCIOTO RIVER. ALL TEMPERATURES IN THE DISCHARGE RANGE .078-.216 C. F. S. PER SQUARE MILE.

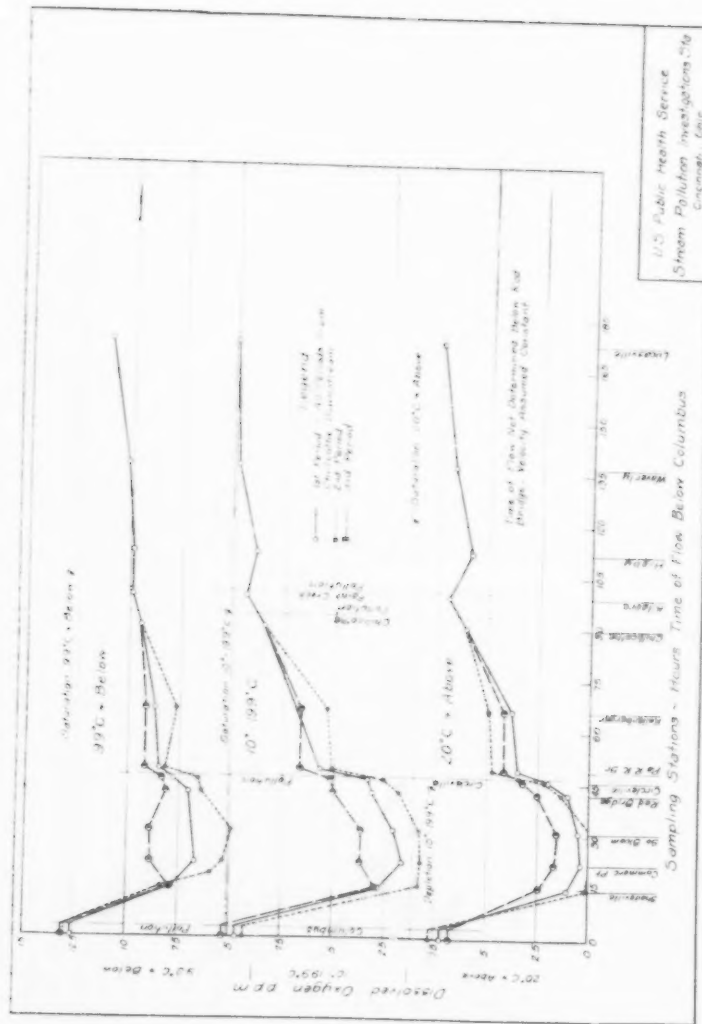
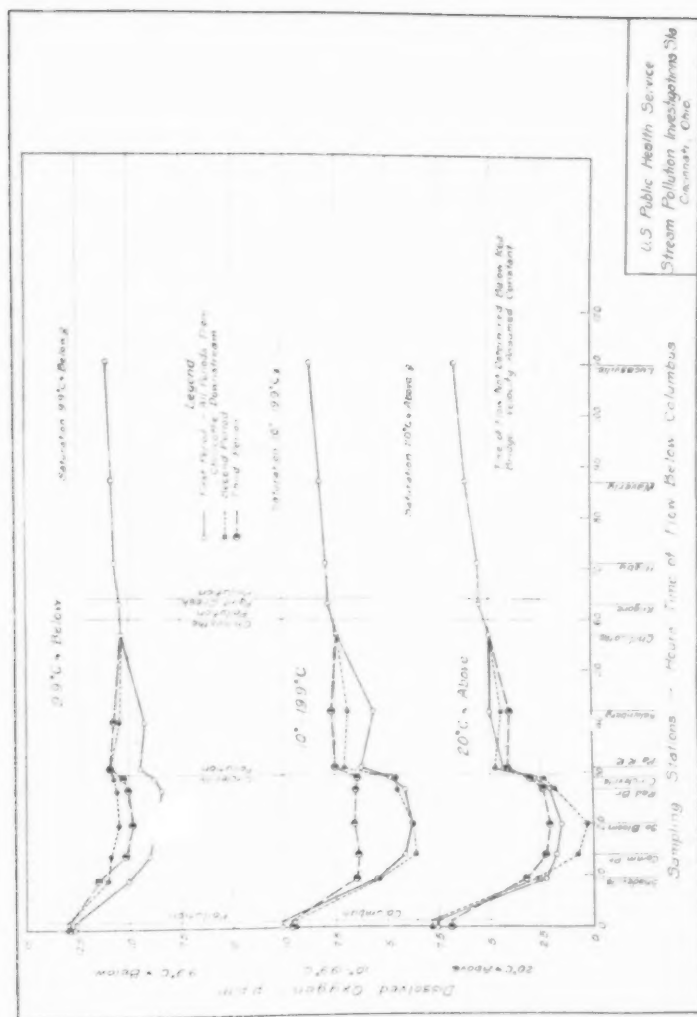


FIGURE 28. DISSOLVED OXYGEN PROFILES ON THE SCIOTO RIVER. ALL TEMPERATURES IN THE DISCHARGE RANGE 217-431 C. F.S. PER SQUARE MILE.



Walnut Creek depletions of dissolved oxygen in the stream are relatively infrequent and the progressive recovery in dissolved oxygen is quite rapid.

There are relatively small decreases in dissolved oxygen at low and intermediate stages below Circleville and Chillicothe (Paint Creek) due to the added pollution received by the Scioto at these two points. Saturation values for dissolved oxygen at stream temperatures, based on the average of grouped results, were not observed at Lucasville, the lowest station downstream. The dissolved oxygen at Lucasville averages 76 percent to 97 percent of saturation tending to be lower at high temperatures and high river stages. There is, at times, considerable diurnal variation in D. O. as discussed later, however, and the foregoing results must be interpreted in this light.

The effect of variations in the intensity and nature of pollution received by the Scioto at Columbus is clearly shown in figures 27, 28, and 29, where the three periods of pollution are indicated by different lines in the same temperature and discharge range for the stretch of river from Columbus to Kellenberger Bridge. This effect is covered more fully in the general discussion of the effect of changes in sewage treatment at Columbus upon the river.

The corrections made at Commercial Point to compensate for dissolved oxygen contributed by Big Walnut are carried as a flat p. p. m. correction down to Circleville and then eliminated. This is not strictly accurate because the correction should be increased by additional dilution and decreased by an indeterminate amount due to a presumably greater rate of oxygen absorption at the computed lower oxygen saturation values.

Reaeration.—The calculation of reaeration rates from both experimental data and from stream survey data has been intensively studied by Streeter (19) (20) who has expressed the rate of atmospheric reaeration, r_0 , as a maximum rate of absorption of oxygen in pounds of oxygen per 1,000 square feet of stream surface per day. From these studies by Streeter, the calculation of reaeration rates has been found to be based largely on the following three factors:

- (1) The replacement of dissolved oxygen used in satisfying the biochemical oxygen demand of the stream between the points where the rate of reaeration is to be calculated.
- (2) The net changes in dissolved oxygen in the stream, corrected for inflow and applied as an addition or subtraction to the amounts obtained under (1).
- (3) Revision of the rates so obtained to a standard basis (r_0), the maximum rate when no dissolved oxygen is present. This is done by dividing the rates obtained under (1) and (2) by the average percentage of saturation deficiency. The above calculations have been made for the three river stretches, Shadeville to Commercial Point,

Commercial Point to South Bloomfield, and South Bloomfield to Red Bridge for all temperature ranges and three discharge ranges as shown in table XXVII and plotted in figures 30, 31 and 32.

Table XXVII.—Calculated maximum reaeration rates (r_o) in three stretches of the Upper Scioto River based on three assumed rates of satisfaction of the mean biochemical oxygen demand present

(r_o) in [pounds per 1,000 square feet per day]

"K" value used	9.9° C. and below								
	Shadeville-Commercial Point			Commercial Point-South Bloomfield			South Bloomfield-Red Bridge		
	Low	High	Actual	Low	High	Actual	Low ¹	High ²	Actual ³
Low discharge:									
1st period	Negative	Negative	Negative ⁴	0.26	0.45	0.82	0.99	1.19	1.44
2d period	Negative	0.37	1.7	.61	1.30	2.45	1.37	1.92	2.80
3d period	1.07	1.41	2.18	.58	.98	1.63	2.1	2.5	2.98
Average	.36	.59	1.3	.48	.91	1.63	1.49	1.87	2.41
Intermediate:									
1st period	4.1	5.0	9.5	2.4	2.8	5.1	2.4	2.8	5.1
2d period	Negative	Negative	2.5	.7	1.3	3.9	3.3	4.5	5.8
3d period	7.2	8.1	9.9	1.9	3.1	5.3	8	1.7	3.0
Average	3.8	4.4	7.3	1.7	2.6	4.8	2.2	3.0	4.6
High discharge:									
1st period	16.4	17.5	22.2	2.3	3.5	6.8	2.3	3.5	6.8
2d period	37.6	40.2	52.6	4.8	7.6	18.2	4.7	7.6	15.0
3d period	21.6	24.0	32.0	Negative	1.1	7.1	13.5	15.7	18.7
Average	25.2	27.2	35.6	1.7	4.1	10.7	6.8	8.9	13.5
10° C.-19.9° C.									
Low discharge:									
1st period	0.86	1.41	1.32	Negative	0.56	0.40	1.21	1.56	1.51
2d period	.68	1.65	1.45	1.16	2.0	1.76	1.75	2.38	2.24
3d period	.39	.71	.64	.015	.30	.23	1.43	1.67	1.64
Average	.64	1.26	1.14	.39	.95	.80	1.46	1.87	1.80
Intermediate:									
1st period	.3	1.1	.97	1.5	2.4	2.2	2.9	3.7	3.6
2d period	.6	1.2	1.1	.7	1.3	1.2	2.1	2.7	2.6
3d period	2.4	2.9	2.8	.7	1.3	1.2	3.6	3.8	4.1
Average	1.1	1.7	1.62	.97	1.7	1.53	2.9	3.4	3.4
High discharge:									
1st period	Negative	Negative	.3	.4	1.1	1.6	2.5	3.2	3.6
2d period	.6	1.4	2	1.7	2.5	3.1	.9	1.7	1.9
3d period	8.9	9.6	10.3	1.9	3.4	4.0	5.6	6.5	6.9
Average	3.2	3.7	4.2	1.3	2.3	2.9	3.0	3.8	4.1
20° C. and above									
Low discharge:									
1st period	0.32	0.94	0.17	0.73	1.26	0.55	1.49	1.81	1.38
2d period	.78	1.97	.50	.94	1.84	.72	1.69	2.26	1.50
3d period	.8	1.58	.66	1.11	1.76	.90	3.08	3.62	2.92
Average	.63	1.50	.44	.93	1.62	.72	2.09	2.57	1.93
Intermediate:									
1st period	.05	.6	Negative	.7	1.2	.50	1.2	1.6	1.1
2d period	.7	1.6	.5	.9	1.8	.7	2.6	3.3	2.4
3d period	.3	.9	.17	.5	1.0	.36	2.0	2.4	1.9
Average	.35	1.03	.22	.70	1.33	.52	1.9	2.4	1.8
High discharge:									
1st period	1.1	1.9	1.1	.5	1.4	.6	2.4	3.0	2.5
2d period	Negative	Negative	Negative	.2	1.3	.5	4.8	5.5	4.7
3d period	.1	.9	.13	.4	1.1	.5	2.1	2.7	2.2
Average	.40	.93	.41	.37	1.23	.53	3.1	3.7	3.1

¹ Negative values obtained.

² "K" of 0.1 temperature coefficient $K_T = K_{20} (1.047^{T-20})$.

³ "K" of 0.2 temperature coefficient $K_T = K_{20} (1.047^{T-20})$.

⁴ Measured rate of B. O. D. adjusted for variations with temperature and discharge.

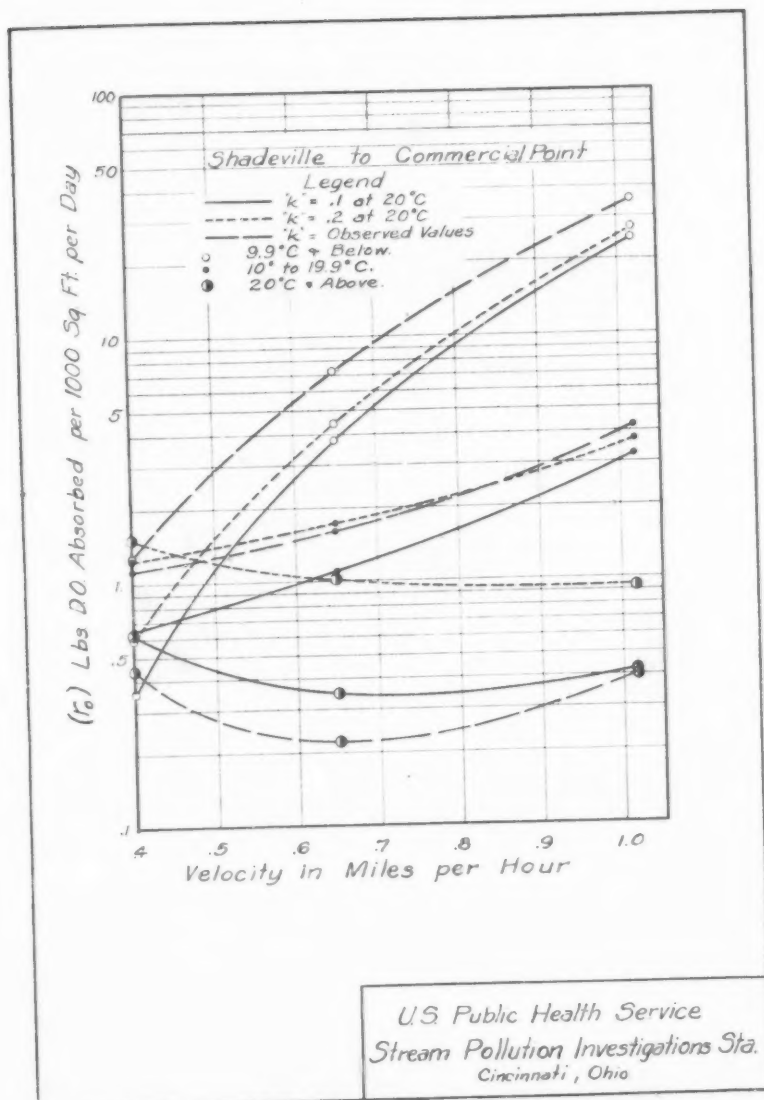


FIGURE 30. CALCULATED MAXIMUM REAERATION RATES (R_0) IN THE SCIOTO RIVER BETWEEN SHADEVILLE AND COMMERCIAL POINT.

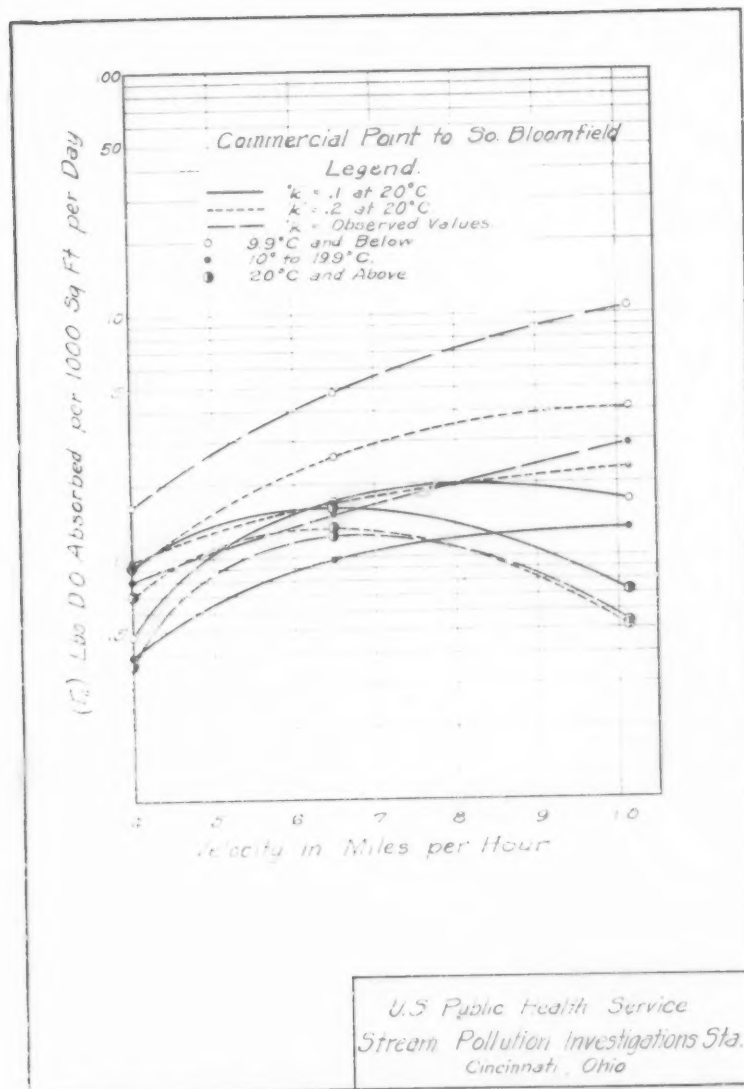


FIGURE 31. CALCULATED MAXIMUM REAERATION RATES (R_d) IN THE SCIOTO RIVER BETWEEN COMMERCIAL POINT AND SOUTH BLOOMFIELD.

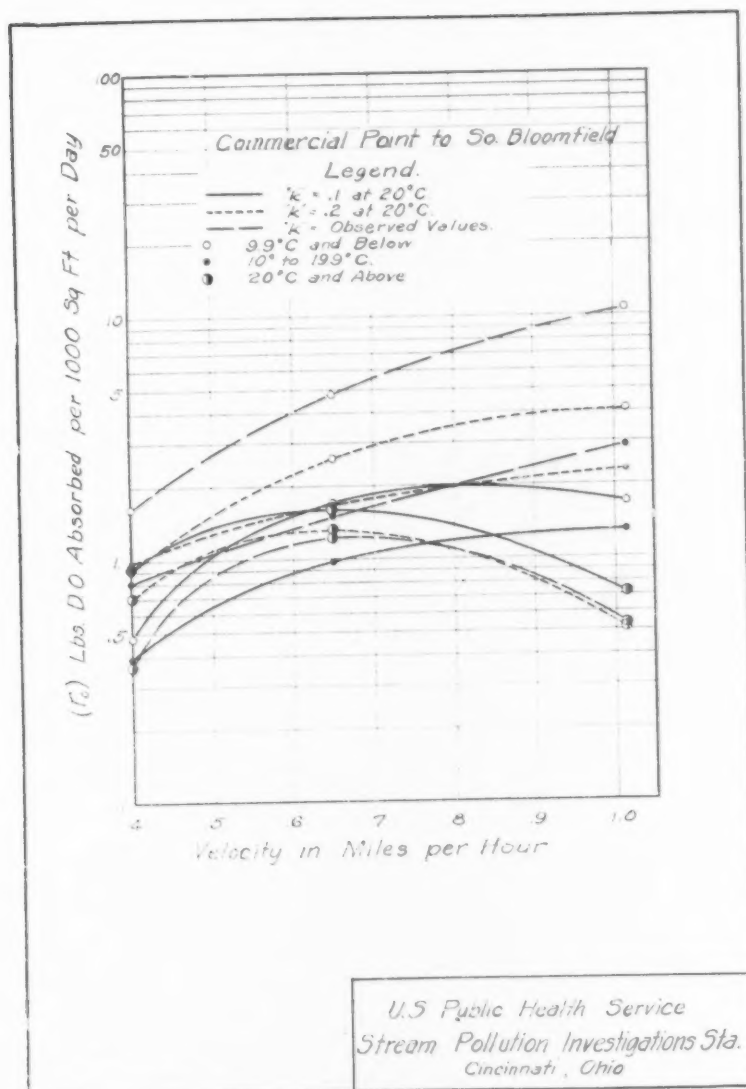


FIGURE 31. CALCULATED MAXIMUM REAERATION RATES (R_c) IN THE SCIOTO RIVER BETWEEN COMMERCIAL POINT AND SOUTH BLOOMFIELD.

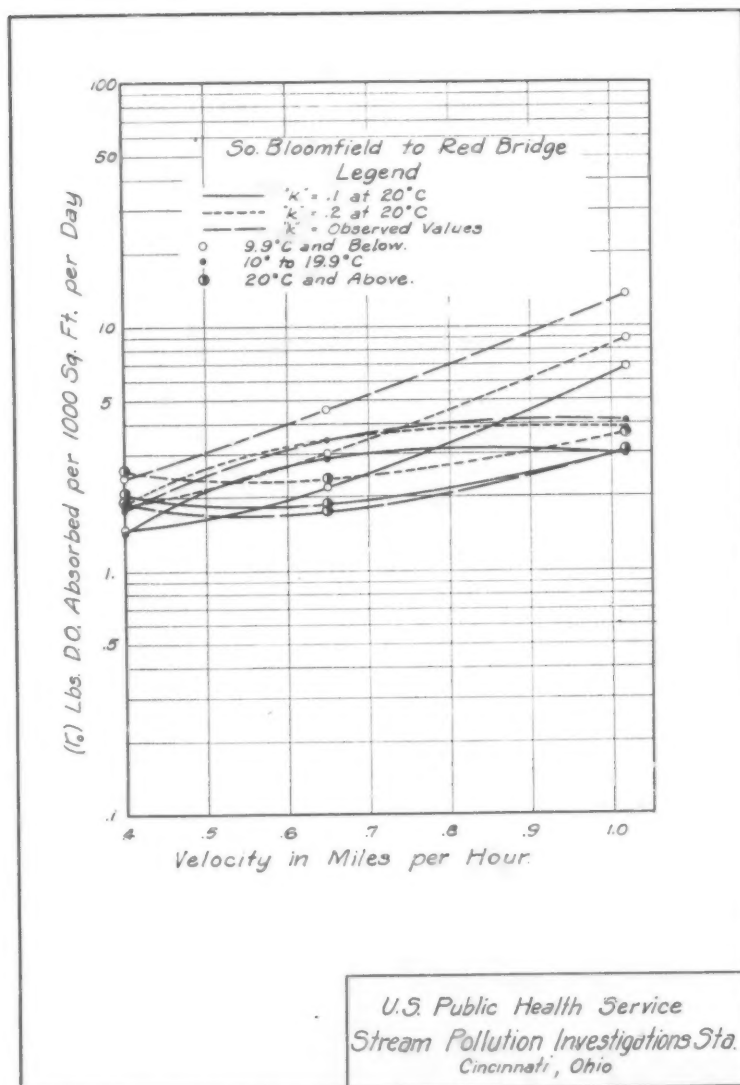


FIGURE 32. CALCULATED MAXIMUM REAERATION RATES (R_0) IN THE SCIOTO RIVER BETWEEN SOUTH BLOOMFIELD AND RED BRIDGE.

As might be expected from a study of the rates of B. O. D. decrease in the Scioto, part 1 of the calculation of rates of reaeration proved to be the most difficult and unsatisfactory section of these calculations. The rates of B. O. D. satisfaction, or the actual rate of oxygen demand upon the stream, differs from the rate of B. O. D. decrease by such factors as sedimentation, oxidation of bottom deposits, and oxidation of B. O. D. derived from photosynthetic activity of plankton within the river stretch, all of which are unmeasured factors. Under these conditions it was decided to compute the reaeration rates from the mean ² B. O. D. for a given period, temperature range, and discharge range using 3 bases of assumed rates of satisfaction of biochemical oxygen demand. The three rates of satisfaction in B. O. D. were used in order that the effect of these three assumptions upon the computed rates of reaeration could be evaluated. The first of these three assumed rates of satisfaction of oxygen demand was based on a "K" value of .100 at 20° C. with a temperature variation $K_T = K_{20} (1.047^{T-20})$ giving for the three average temperatures 5.0° C., 15.2° C., 23.7° C., K values of 0.0502, 0.0802 and 0.1184, respectively. This is the normal range of oxidation rates for river water and sewage in bottles and these rates have also been observed in larger streams. The second assumption was a "K" value of 0.200 at 20° C., with the same temperature relationship, which gave rates of B. O. D. satisfaction double those under the first assumption or "K" values of 0.1004, 0.1604 and 0.2368 at temperatures of 5.0° C., 15.2° C. and 23.7° C., respectively. Inasmuch as higher rates of purification have generally been observed in smaller streams, it was thought possible that a deoxygenation constant of 0.2 at 20° C. might serve as an upper limit for oxidation in the Scioto under stream flow conditions, a supposition which now seems questionable. The third set of assumed rates of B. O. D. satisfaction are based on the adjusted "K" values obtained in the stream for rates of B. O. D. decrease based on arithmetic averages of the B. O. D. in each of the temperature and discharge ranges as shown in table XXIV, line 3. Adjustment was made for the change in mean values with both temperature and discharge, the adjusted values used being given in table XXVIII.

Table XXVIII.—Adjusted "K" values based on actual B. O. D. decreases in the Shadeville to Red Bridge stretch

Discharge range c. f. s. per sq. mile	Temperature range		
	9.9° C. and below	10° C.-19.9° C.	20° C. and above
0.078-0.216	0.180	0.144	0.087
0.217-0.431	.185	.148	.090
0.432-1.234	.206	.214	.129

² The geometric mean of the four station arithmetic averages of individual analyses in each group.

The effect of assumptions regarding rate of satisfaction of biochemical oxygen demand are readily observed in figures 30 to 32 as roughly parallel lines defining rates of reaeration (r_o). Semilog paper was used in plotting figures 30 to 32 largely to enable the inclusion of all points on a single sheet of reasonable size.

In computing the net change in amount of oxygen carried by the stream a correction was made for inflow of Big Walnut Creek in the Shadeville to Commercial Point stretch and it seems likely that the high values for r_o obtained at low temperatures in this stretch were due at times to the application of low values for this correction. The frequency, in the Shadeville to Commercial Point stretch, of r_o values listed as "negative" where the increase in dissolved oxygen in the stream was greater than the computed oxygen utilization for that stretch would indicate that the correction applied for Big Walnut inflow was too great at other times.

Where the percentage saturation deficiency was quite high, the r_o value obtained was only slightly affected by slight changes in the dissolved oxygen and, as might be expected, much more stable and uniform values were obtained, this being the case at high and intermediate temperature ranges in all of the river stretches. The unusually high values obtained for r_o at low temperatures may be largely due to the application of a high multiplication factor which would, especially at low temperatures, increase several-fold the calculated rates of oxygen absorption, thus magnifying any slight errors in oxygen measurement.

Although the computed rates of reaeration in general vary quite widely, they show a tendency to increase with increasing velocity of flow except in the highest temperature range where the values obtained at low velocity in general tend to be somewhat larger than those at higher velocities. In the conditions under which it occurs, this would correspond to the frequently observed effect of photosynthetic plankton in providing reaeration by biological means.

**EFFECT OF CHANGES IN SEWAGE TREATMENT AT COLUMBUS UPON
THE SCIOTO, AS INDICATED BY CHEMICAL AND BACTERIOLOGICAL
TESTS**

COLUMBUS SEWAGE TREATMENT

As has been previously pointed out, the primary purpose of this survey was to measure, quantitatively, the changes occurring in the Scioto River, following changes in sewage treatment at Columbus. A detailed description of the operation of the Columbus plant during the three periods of varying operation seems therefore advisable. Plant operation during these three periods was not by any means constant. Frequent interruption and changes, the breaking in of the new plant and the by-passing of raw sewage made impractical a consideration of these minor changes other than their use in estimating the average loading on the river during the three periods. Although a variety of information regarding Columbus plant operation was available and a large number of analyses were made of Columbus sewage, both at Columbus and at the Chillicothe laboratory, the most accurate method of estimating the load on the river was by deducting from the total estimated raw sewage load in the Columbus area the average amount removed by the treatment process then in operation, taking into account the period of time during which the treatment plant was by-passed.

The total carbonaceous B. O. D. of the raw sewage at Columbus was estimated at approximately 115,000 pounds per day, or 0.38 lb. per capita per day, derived from a 5-day B. O. D. of 79,000 pounds.

It is estimated that during the first period, February 11, 1937–November 30, 1937, an average of roughly half of the sewage originating in the Columbus area was passed through the overloaded trickling filters of the old Columbus plant, and the average load on the river was estimated at about 45,000 pounds per day of 5-day B. O. D. or 66,000 pounds total carbonaceous B. O. D.

During the second period, which extended from December 1, 1937 to July 15, 1938, most of the sewage was given primary treatment only in the new plant with approximately 35 percent removal of B. O. D. Some raw sewage was also by-passed during this period and it is estimated that the sewage load on the river was 55,000 lbs. of 5-day B. O. D. per day or 80,000 lbs. of total carbonaceous demand. This gives the B. O. D. loading during the second period as about 120 percent of that during the first period. While the total B. O. D. load of raw sewage of 115,000 lbs. per day may be somewhat in error,

the estimate of relative loading during the first and second period was based upon the same total raw sewage load and should, it is believed, be less in error.

During the third period, it was not possible to obtain what could be regarded as an accurate estimate of the average B. O. D. loading upon the stream. This was due to the great variations in loading which occurred and to the lack of samples during certain critical periods. River conditions were good when the plant was operating properly and the stations below Shadeville were, in general, much less affected by pollution occurring during the third period than by that occurring during the first and second periods. This may, however, have been partly due to the character of the polluting substances discharged during the third period, these being largely activated sludge particles which, during low stream flows, settled in the pool into which they were discharged. Conditions in this pool which, in effect, acted as a large septic tank, were quite bad at times but the river showed little effect from the pollution beyond the first two or three miles below this pool.

COMPARISON OF RIVER CONDITIONS DURING THE THREE PERIODS

While there are a number of ways of comparing the quality of stream water in the river below Columbus during the three periods of pollution, it is highly desirable that such methods should be as stable as possible in order to eliminate many of the variations which occur in the base data. One of the most stable of these is a comparison of the geometric means of the averages (arithmetic) of observations at the four stations, Shadeville, Commercial Point, South Bloomfield, and Red Bridge, for each temperature and discharge range group. This method eliminates many of the large variations in the base data as it measures the percentage difference between the three periods under comparable conditions of flow and temperature. Such a calculation is a general measure of conditions during the three periods in the stretch, Shadeville to Red Bridge, the stretch in which the most intensive sampling was conducted.

In table XXIX are shown the comparative conditions in the stretch of river between Shadeville and Red Bridge as observed during the three periods of varying pollution at Columbus. The figures given in table XXIX express the ratio, in percent, of the B. O. D. and bacteria, in the second and third periods to that in the first period. They are derived from the arithmetic averages of thousands of pounds of total B. O. D. per day and the arithmetic average of quantity units for bacteria.

Table XXIX.—Percentage of bacteria and B. O. D. present in the Shadeville to Red Bridge stretch in the second and third periods compared to the first period

PERCENTAGE OF FIRST PERIOD								
Temperature range	9.9° C. and below		10°–19.9° C.		20° C. and above		Average	
Period	2d	3d	2d	3d	2d	3d	2d	3d
Discharge range c. f. s. per sq. mile	Total B. O. D.							
0.078–0.216	300	116	223	51	190	89	238	85
0.217–0.431	155	89	81	55	175	81	137	75
0.432–1.234	144	99	114	77	130	82	129	86
37° Count								
0.078–0.216	174	35	398	25	178	21	250	27
0.217–0.431	187	147	70	17	140	33	132	65
0.432–1.234	98	68	69	45	18	28	62	49
Coliform bacteria								
0.078–0.216	302	38	302	4	540	40	381	27
0.217–0.431	295	142	181	36	762	48	413	75
0.432–1.234	104	41	175	149	142	56	140	82

As would be expected, there is a general tendency for the percentage differences between the three periods to decline rather sharply with increases in discharge, the ratio of the second to the first period decreasing, and the ratio of the third to the first increasing, toward 100 percent. This is due largely to the increased quantities of B. O. D. and bacteria carried at higher stream flows and the consequent lessening in effect of the pollution added at Columbus at these higher flows.

Based on the Columbus Treatment Plant data, there was added to the river an estimated 66,000 lbs. per day total carbonaceous B. O. D. during the first period and 80,000 pounds per day during the second, a ratio of 121 percent, compared to the 238 percent B. O. D. ratio as indicated for the lowest discharge range in table XXIX. Even allowing for the high variations in the base data and for a considerable error in the estimate of the average B. O. D. discharge at Columbus, it seems that conditions in the river during the second period were much worse than would be expected from the relative amounts of B. O. D. discharged during the first and second periods. This discrepancy would seem to be largely due to the nature of the substances discharged, namely, a partially oxidized sewage during the first period, as against a sewage receiving only primary sedimentation during the second period. However, the additional 20 percent of B. O. D. added may have impaired the processes of natural recovery by creating anaerobic conditions more frequently during the second period. A comparison of the individual ratios in the three temperature ranges would indicate that impairment of natural recovery processes by the occurrence of

anaerobic conditions was not the primary cause of this discrepancy. The individual ratios of second to first period B. O. D. in the lowest discharge range are 300 percent, 223 percent, and 190 percent for the low, intermediate, and high temperature ranges, respectively—that is, a decrease of ratios with increasing temperatures, whereas the frequency of occurrence of anaerobic conditions increases with increasing temperatures.

The ratios of bacteria and B. O. D. present during the third period in the river stretch, Shadeville to Red Bridge, compared to that present in the first period averages, in the lowest discharge range, was 27 percent for both coliforms and bacteria on agar at 37° C. and 85 percent for B. O. D. The increasing trend of the ratios with increasing discharges is not so uniform as was the decreasing trend during the second period, but variations in the strength of effluent of the Columbus plant during the third period were much greater than during either the first or second period and such a result was to be expected. From the best evidence available, the B. O. D. of Columbus effluent during the third period averaged somewhat over half that during the first period, which would be about in line with conditions found in the river.

DISSOLVED OXYGEN

A study of the dissolved oxygen profiles of the river as shown in figures 27, 28, and 29 reveals a nicely graduated series of oxygen sag curves between Columbus and Circleville. In general, these curves bear out the river conditions as indicated in table XXIX, the second period showing the worst river conditions, the first period intermediate conditions and the third period, the best river conditions. Below Circleville, the second sag in dissolved oxygen, being due largely to wastes discharged at Circleville, would not necessarily follow the same pattern as was found above Circleville although the same periods were used in grouping the data. In a number of instances, however, a high or a low degree of pollution upstream from Circleville carried through and seemed to materially affect the dissolved oxygen conditions below Circleville.

In a consideration of the average of a series of dissolved oxygen figures, an accurate picture of river conditions would, however, frequently not be presented due to the inclusion of some figures where the dissolved oxygen was zero. This would be especially true where the average value for dissolved oxygen was less than two or three parts per million and the variation in oxygen demand loading of the river was quite high. Another factor tending to make the dissolved oxygen picture inaccurate is the large diurnal variation in dissolved oxygen which occurs at low stages in the river through photosynthetic production of dissolved oxygen by algae. This diurnal variation in

dissolved oxygen, when present, would make the D. O. figure obtained dependent upon the time of day when the sample was collected. In order to obtain minimum dissolved oxygen values it would be necessary to collect the samples at about dawn. A sample collected at that hour would not, however, represent dissolved oxygen levels due to atmospheric reaeration alone, as the stream would not have become stabilized before the effect of photosynthesis would again become apparent.

PLANKTON STUDIES

TECHNIQUE

The Scioto River plankton was studied at weekly intervals, except that at the beginning the first four samplings were two weeks apart. There were 13 sampling stations along the river as shown on the map (figure 1) and, in addition, the tributary creeks were studied after the work was well under way. Each of the 6 larger creeks was sampled near its mouth, but sufficiently far back so that no influence of the river was noticeable.

Samples for examination were taken in the current, 250 ml. being the quantity used. No net samples were taken, and the studies of bottom materials are reported in the following section. On alternate weeks a trip was usually made to the field laboratory at Chillicothe and the samples were studied in fresh condition with the organisms alive, but on the intervening weeks the samples were preserved with formalin and sent to the Cincinnati laboratory for examination. All organisms were concentrated by centrifuging. Methods of handling and enumeration have been discussed in another paper (21) and probably need no mention here. The river was sampled on 107 occasions, but because of loss, turbidity, and various other reasons the number of samples was not the same for all stations; the total examined for each station is shown in Table XXX.

Table XXX.—The numbers of samples taken from the Scioto River and certain tributaries during each period of operation of the Columbus sewage treatment plant, the spatial distribution of 51 groups, genera or species of plankton, and the number of samples in which they occurred. For each species the top row of figures represents the number of samples in which that species occurred; the second, the total number counted; and the third, the average number per sample. Average occurrence is not given in all cases.

Stations	Columbus	Shadeville	Commerce Point	South Bloomfield	Red Bridge	Circleville	Pennsylvania bridge	Kelley bridge	Chillicothe	Kilgore	Highby	Waverly	Lucasville	Hig Walnut Creek
Station mileages	3	13	17	23	30	35	35	40	61	67	70	92	115	
Treatment: Trickling filter. Dates March 24, 1937 to November 30, 1937. Number of samples	23	25	24	20	14	19	11	14	22	8	6	13	15	7
Treatment: Primary sedimentation. Dates December 9, 1937 to July 13, 1938. Number of samples	27	26	23	26	16	16	15	28	25	15	8	26	25	20
Treatment: Activated sludge. Dates July 16, 1938 to July 18, 1939. Number of samples	52	51	51	51	51	0	50	48	47	45	8	47	46	51
Total number of samples	102	102	98	97	81	35	76	90	94	68	22	86	86	84
Fungi:														
Schizomycetes:														
Sphaerotilus sp.	3	32	20	21	13	8	7	13	9	3	2	3	10	1
	151	15,404	7,463	4,637	968	966	973	1,466	1,458	312	22	1,063	348	60
	1.4	146.0	72.0	45.4	11.0	30.0	13.0	15.0	15.0	3.0	1.0	13.0	4.0	...
Blastocaulis sphaerides.	12	9	15	17	17	17	17	20	22	17	4	18	20	11
	339	463	733	521	1,057	1,057	1,057	2,030	3,524	2,265	415	1,852	1,445	285
	5.7	7.6	12.8	9.3	17.6	17.6	21.0	44.4	62.0	42.5	38.0	32.7	24.9	8.3
Algae:														
Myxophyceae:														
Lyngbya conferta.	1	5	7	5	4	8	4	8	12	4	4	3	9	4
	4	11	76	28	58	85	70	262	613	32	35	193	131	98
	15	31	14	14	16	3	24	24	13	17	2	7	14	6
Oscillatoria spp.	193	487	290	650	415	97	570	249	283	156	41	122	276	34
Euglenophyceae:														
Euglena all species	60	76	60	60	57	19	54	61	60	53	15	53	53	46
	937	1,977	1,400	1,405	2,331	258	2,253	2,571	1,423	908	963	692	464	431
	9.37	18.8	14.1	13.8	27.8	8.0	29.6	28.2	14.8	14.4	31.0	7.25	5.31	5.11
Euglena pisciformis	18	20	21	18	18	6	23	20	24	17	4	11	12	14
	77	246	162	118	298	13	346	340	157	130	67	70	69	72
	0.73	2.41	1.65	1.15	3.55	0.41	4.59	3.44	1.57	2.07	3.04	0.84	0.68	0.87
Euglena polymorpha	15	16	16	11	14	4	3	12	12	9	2	10	10	13
	66	126	117	147	375	38	286	78	65	55	4	43	31	34
	0.62	1.20	1.12	1.47	4.40	1.00	3.76	0.86	0.68	0.82	0.18	0.52	0.30	0.41

Table XXX.—The numbers of samples taken from the Scioto River and certain tributaries during each period of operation of the Columbus sewage treatment plant, the spatial distribution of 51 groups, genera or species of plankton, and the number of samples in which they occurred. For each species the top row of figures represents the number of samples in which that species occurred; the second, the total number counted; and the third, the average number per sample. Average occurrence is not given in all cases.—Continued

Stations	Columbus	Shadeville	Commerce Point	South Bloomfield	Red Bridge	Circleville	Pennsylvania bridge	Kellenburger	Chillicothe	Kilgore	Highby	Waynesville	Lucasville	Big Walnut Creek
Station mileage	3	13	17	23	30	33	35	46	61	67	76	92	115	
<i>Algae</i> —Continued.														
<i>Euglenophyceae</i> —Continued.														
<i>Euglena viridis</i>	24 84 0.75	27 303 1.53	30 155 1.40	28 126 1.26	21 51 2.43	8 48 1.45	18 179 2.45	17 73 0.80	26 103 1.07	16 40 0.59	6 25 1.04	13 27 0.32	12 34 0.30	13 37 0.45
<i>Trachelomonas crebes</i>	674 6.36	609 5.80	841 8.59	556 6.43	489 5.82	133 5.81	459 5.76	643 7.07	528 6.54	636 9.49	111 5.73	42 788 8.57	43 685 5.97	64 198 3.11
<i>Trachelomonas urecolata</i>	43 5.51	35 407 4.73	38 570 5.48	38 570 5.65	36 907 11.1	11 125 3.94	11 125 3.94	32 783 8.06	34 666 5.06	32 445 6.04	16 124 7.75	26 266 2.90	26 265 2.03	27 273 3.25
<i>Chrysophyceae</i>														
<i>Chrysococcus</i> spp.	60 14.43	54 2.878	65 7.484	65 8.102	57 7.412	20 3.617	49 8.04	69 12.408	66 19,284	54 23,465	16 4,707	57 16,012	60 25,158	67 27,046
<i>Chromulina globosa</i>	165 18	51 8	63 15	60 10	147 15	2 3	118 11	105 13	244 20	284 11	225 17	225 17	219 17	212 17
<i>Dinobryon</i> all species.....	938 1.094	101 4.62	611 4.07	610 5.76	727 754	29 2.00	392 7.40	637 7.96	1,030 9.44	1,030 9.52	140 5.32	1,396 5.30	1,474 4.75	1,392 8.87
<i>Mallomonas</i> spp.	10.3	4.62	4.60	5.64	8.98	2.00	7.40	7.96	9.44	9.52	5.32	5.30	4.75	8.87
<i>Bacillariaceae</i>														
<i>Cyclotella meneghiniana</i>	82 22.030	81 22,302	72 18,494	81 23,004	60 33,452	16 17,360	66 23,102	79 67,291	76 81,442	58 82,422	10 38,363	68 128,064	71 98,700	60 34,367
<i>Melosira granulata</i>	298 72	212 52	178 54	225 53	308 48	231 15	304 42	67 50	845 60	1,350 56	1,790 19	1,546 74	1,170 71	1,050 21
<i>Navicula</i> spp.	408 123	265 110	377 124	5,716 112	14,067 92	1,992 29	5,059 82	13,065 100	16,417 102	11,913 73	4,807 21	14,133 87	12,214 68	500 85
<i>Nitzschia</i> spp.	6,920 58	13,114 48	124 55	6,716 40	5,033 2.708	910 372	6,740 2.197	6,943 5.301	11,314 8.707	10,796 6.049	1,494 2.065	8,450 8.704	7,210 8.901	2,799 2.814

Table XXX.—The numbers of samples taken from the Scioto River and certain tributaries during each period of operation of the Columbus sewage treatment plant, the spatial distribution of 51 groups, genera or species of plankton, and the number of samples in which that species occurred. For each species the top row of figures represents the number of samples in which that species occurred; the second, the total number counted; and the third, the average number per sample. Average occurrence is not given in all cases.—(Continued)

[illegible]

All organisms were counted. A few species could not be identified, even to genus in a very few cases. Some new genera and species were found; most of them have been described elsewhere (22) (23). Those not known were given provisional names so they could be counted. In some cases e. g., *Chlamydomonas*, only the genus was given recognition, because it was impractical to separate species in the rapidity of counting. A few genera, as the "small colorless" flagellates were similarly counted, for, except by very careful examination which precludes counting, it is not feasible to separate *Bodo*, *Monas*, *Oicomonas*, *Pleuromonas*, etc. at all times.

All groups of Protozoa except the Sporozoa were found. Of the fungi, *Spirillum*, *Spirochaeta*, *Chromatium*, *Blastocaulis*, *Sphaerotilus*, *Beggiatoa* and yeasts were counted. No brown or red algae were found, but blue green algae were abundant, and all groups of the green algae except the *Chloromonadida* were found. In all, 448 individual species, genera or groups of organisms were enumerated from the Scioto plankton alone, a far greater group than has ever been listed from any other river. Space will not permit consideration of more than a few of these in this report, but the data nevertheless comprise a fundamental basis for future river studies. It has been found that many rivers of the Ohio Basin, from which it has been possible to get samples, have shown a large number of species and a vast number of individuals, thus agreeing with, and substantiating the results of the Scioto studies. Because both the species list for the rivers examined, and the total numbers of organisms found, are far in excess of previously studied rivers, it is believed the data herein presented are of importance. All data are on file in the Cincinnati laboratory, and available for reference and possible future publication.

STATUS OF CERTAIN PLANKTON ORGANISMS AS INDICATORS

The primary consideration in this study is whether or not the plankton reflect the sanitary condition of the river, and if so, what changes in the river are indicated by the plankton during the periods when the Columbus sewage was being treated by trickling filter, by primary treatment, and after the complete treatment was begun. This necessitated a review of the status of certain plankton organisms as indicator types, because the results obtained were not always in agreement with the ecologic classification of other workers.

A number of those organisms occurring most abundantly have been selected and their distribution is given at certain stations in table XXX. The table is too brief to show fully how their ecologic classification was arrived at, but they are therein shown as most abundant in clean water, in sewage polluted water, or indifferent. It seemed best to avoid the use of strict classifications as "oligosaprobic" for it

has been found that plankton organisms may occur to some extent in almost any water which does not represent an extreme of some sort. This is more true of a stream than a pool or lake, for plankton organisms in a stream are unable to migrate other than as the current flows. It is, therefore, their abundance in a stream sector where there is sufficient time, either because of slow current or still areas, for them to multiply, which becomes significant.

Many of the 448 species or groups of organisms found in the Scioto plankton were found only a few times and in small numbers. Table XXX lists only those which occurred with the greatest frequency and includes representatives of all the important groups. The table lists some 53 organisms, or groups of organisms, so only about 20 percent of the microscopic organisms occur with sufficient frequency in the river to be used as indicator organisms. The protozoa are sometimes spoken of as cosmopolitan in distribution, an idea which is probably correct in its broad sense, that is, a given species might occur in a stagnant pool in America, Australia, and Africa. But the microclimatic factors governing the appearance of a species in a particular pool are very poorly known for most protozoa and algae, and as shown by Lackey (24), only a few species of protozoa exhibit such a wide tolerance of environmental fluctuation as to be frequently found in almost any sample from a natural pool or stream.

Table XXX enables the use of the following organisms or groups of organisms as thriving best in polluted water:

<i>Sphaerotilus natans.</i>	<i>Minute colorless flagellates.</i>
<i>Oscillatoria spp.</i>	<i>Anthophysa vegetans.</i>
<i>Euglena pisciformis.</i>	<i>Bodo caudatus.</i>
<i>Euglena polymorpha.</i>	<i>Oicomonas termo.</i>
<i>Euglena viridis.</i>	<i>Poteriodendron petiolatum.</i>
<i>Chlamydomonas spp.</i>	<i>All Rhizomastigina.</i>
<i>Spondylomorpha spp.</i>	<i>Rhizopoda except Nuclearia.</i>
<i>Eudorina elegans.</i>	<i>Glaucocystis spp.</i>
<i>Colpidium spp.</i>	<i>Paramecium spp.</i>
<i>Pandorina morum.</i>	<i>Vorticellida generally.</i>

This list, however, does not include many organisms used by Whipple (25) and others to indicate pollution. Thus the Volvocales as a whole and the Euglenidae generally are so used by Whipple. The fallacy of this view is at once apparent when one considers that *Volvox* usually attains its great blooms in pools or small lakes mostly free from sewage pollution, and that *Euglena mutabilis* is rarely found except in highly acid waters. Unfortunate for this view, too, is the fact that the highest concentrations of *Euglena polymorpha* that the writer has ever seen have not been where sewage was present, but on ponds. Nevertheless the presence of most of these forms in abundance in a stream probably indicates sewage. Their maxima

in the Scioto are attained in the Shadeville-South Bloomfield stretch, and they diminish downstream.

A small group of about 11 genera occur in large numbers both in the polluted sector and the clean water sector. This includes all species of *Euglena*. After formalin preservation, large numbers cannot be identified to species, and considering the genus *Euglena* as a whole, numbers are very high from Shadeville to Kilgour: the highest average is at Kellenberger, but there are almost as many at Red Bridge. This sustained average over a long stream stretch for all species of the genus bears out the contention, herein presented, that the entire group may not be considered as indicators of pollution. In this same class of possibly indifferent organisms must be included two other green Euglenophyceae which have appeared in large numbers: *Trachelomonas urceolata* and *T. crebea*. Other genera which behaved likewise are *Naricula* spp., *Cyclidium* spp., *Halteria grandinella*, *Strombidium gyrans*, *Heteromastix angulata*, *Thoracomonas phacotoides* and *Colloidietyon triciliatum*. These last 3 belong to the Volvocales and still further support the contention advanced above.

The list of forms favoring clean water is much larger, and could include more of the Chlorophyceae than are shown in table XXX. *Blastocaulis sphaerica*, the stalked bacterium, has its high peak far downstream. *Lyngbya contorta*, one of the blue green algae, behaves similarly. Five plankton diatoms are in this category: *Asterionella formosa*, *Synedra ulna*, *Nitzschia acicularis*, *Cyclotella meneghiniana*, and *Melosira granulata*. *Cryptomonas erosa*, *Chroomonas* spp., and *Rhodomonas lacustris* the three common Cryptophyceae, usually high at Columbus, drop in the Shadeville area, then rise to their peak downstream, as do all of the Chrysophyceae. Four genera of these last, *Chrysococcus*, *Chromulina*, *Dinobryon* and *Mallomonas* have occurred in large numbers, and no species or genus of Chrysophyceae even in small numbers, has shown a preference for foul water. Figures 33 and 34 show the behavior of the genera *Cryptomonas* and *Chrysococcus*, treated more fully in the next section. *Carteria cordiformis*, *Phacotus lenticularis* and the colorless *Polytoma granulifera* are the only Volvocales whose reaction sharply favors clean water. *Desmarella moniliformis*, *Domatomonas cylindrica* and *Bicoeca lacustris* are bacterium-eating colorless flagellates which prefer clean water. Of the Sarcodina, *Nuclearia simplex* has seemed to prefer clean water in the Scioto despite its occurrence in sewage. The Heliozoa occur most frequently in the lower river, and the four ciliate genera *Codonella*, *Strobilidium*, *Tintinnidium* and *Urotricha* are most abundant either at Columbus or far downstream.

None of the plankton Chlorophyceae have their maximum in the Shadeville-Red Bridge area. Several species are shown by table XXX to have been present in large numbers during the survey. For

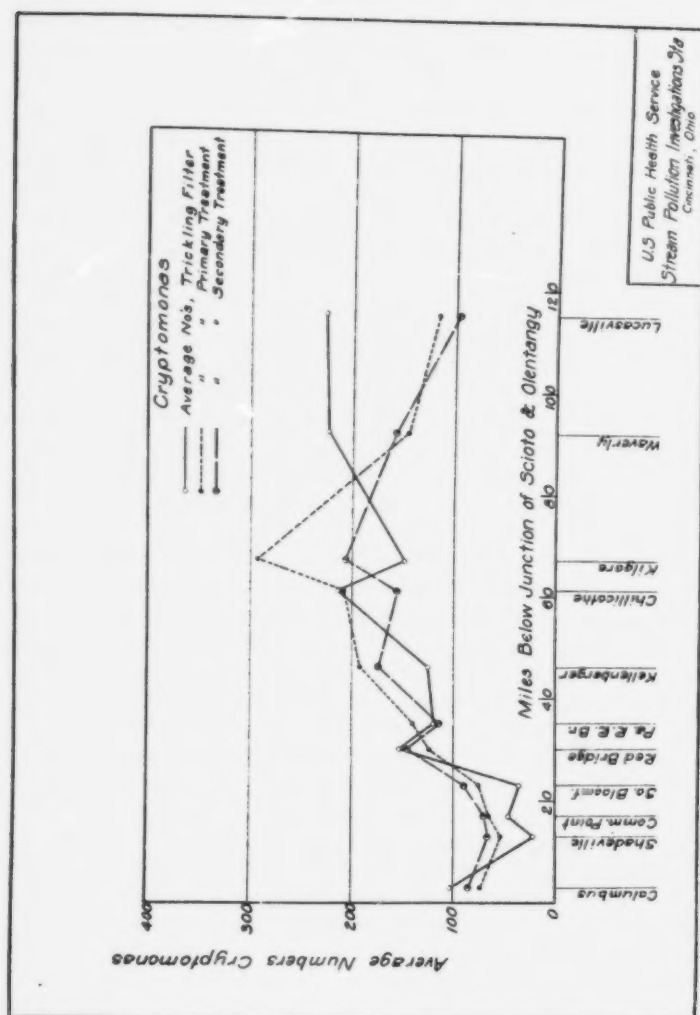


FIGURE 33. THE AVERAGE NUMBERS OF CRYPTOMONAS AT EACH STATION DURING THE THREE PERIODS OF SEWAGE TREATMENT.

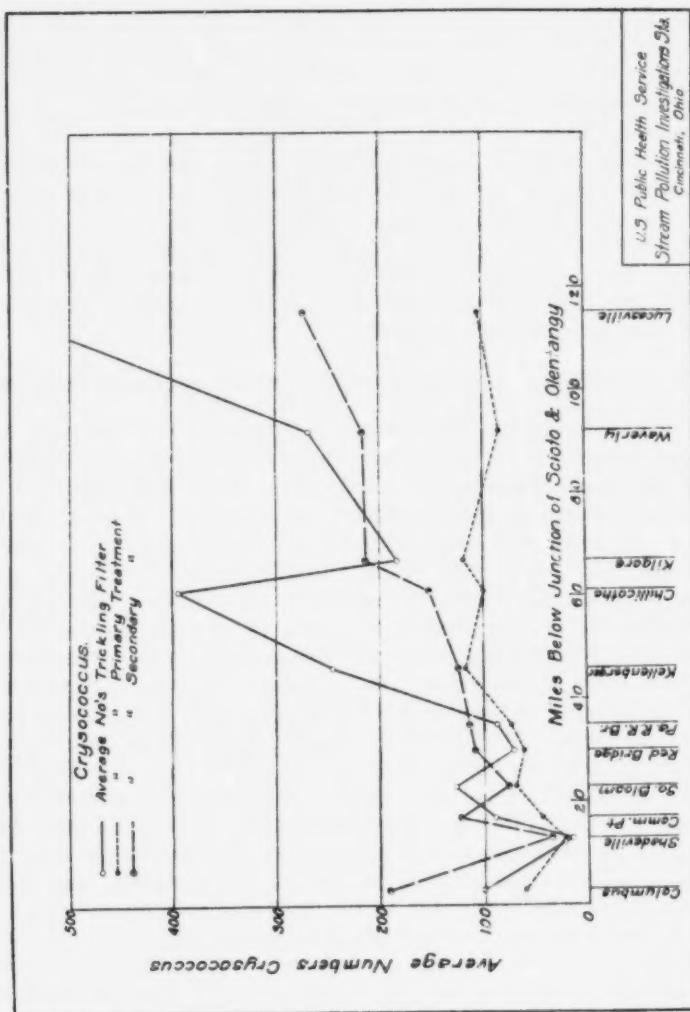


FIGURE 34. THE AVERAGE NUMBERS OF CHRYSOCOCCUS AT EACH STATION DURING THE THREE PERIODS OF SEWAGE TREATMENT.

the most part their incidence is seasonal. None of those which occurred in quantity showed a decided drop from Columbus to Shadeville. One group, consisting of *Golenkinia paucispina*, *Lagerheimia longiseta*, *Quadrigula closteroides*, *Tetrastrum punctiformis*, *T. staurogeniforme*, *Tetraedron trigonum* and *Tetrallantos lagerheimii* showed a pronounced drop below Columbus, until Kellenberger, but they were never very abundant. The behavior of the more numerous ones as well as some other organisms (*Blastocaulis sphaerica*, *Lyngbya contorta*, for example) raises the question of whether it is pollution which is responsible for their low numbers at Shadeville or age of water which accounts for their occurrence in large numbers in the lower river. In other words, they show a steady increase which begins at Columbus and, despite pollution, continues downstream, the peak being attained in clean water. Forms behaving in this manner need more investigation before their ecologic status relative to the sanitary condition of the river can be sharply defined.

POSSIBLE EFFECTS OF DIFFERENT TREATMENT OF COLUMBUS SEWAGE

The above comprises a brief report of the plankton content of the river and the influence of the river on that plankton. It is more illuminating than the results of the three periods of treatment of the Columbus sewage on the plankton. Separation of seasonal, and other factors, such as dilution plus turbidity caused by heavy rainfall in the late spring and early summer of 1939, from the methods of sewage disposal which were used, is difficult. During the period when the trickling filter was being used about 25 sets of samples were examined: about 28 while the sewage was getting primary treatment only; and about 52 while complete treatment was given. Figure 33 shows the behavior of *Cryptomonas* during this time. Two significant points stand out: (1) The average number at Shadeville was more than twice as great for the last of these three periods than for the first. (2) The decrease from numbers present at Columbus was much less after the trickling filter was discontinued than before. Figure 34 gives a similar comparison for *Chrysococcus*. The results are almost the same, as far as Shadeville is concerned. In these two cases, the immediate rise was largely due to Big Walnut Creek, which contributed a large population of each just below Shadeville. For *Chrysococcus* this rise was only temporary except for the period of primary treatment alone, and the real rise began at Red Bridge, despite the effect at Circleville, while for *Cryptomonas* the Circleville wastes produced a slight drop in average numbers. Compared to the numbers present downstream, the results at Shadeville are disappointing as showing that the effects of different treatment are not very well differentiated. These results could be applied to other species.

Thus the pollutional organisms *Bodo caudatus* and *Trepomonas rotans* were most abundant during the period when primary treatment alone was in use, but at one time after the activated sludge process was in operation, *Trepomonas* occurred at Shadeville, Commercial Point and South Bloomfield, and there is a possibility that the river was getting much sludge at that time. *Phacotus lenticularis* was most abundant during the period of primary treatment and least abundant while the trickling filter was in operation and the same was true of *Bicoeca lacustris*, which normally is most abundant in clean water. *Poteriodendron* was most abundant after the activated sludge plant was put into operation, probably because it was a common inhabitant of the aeration tanks. *Domatomonas cylindrica* appeared in large numbers at Shadeville, whereas almost none had been previously taken there; it seems to be a clean water organism, but if the numbers above Shadeville were high, enough could have persisted to account for the status observed. The green algae *Ankistrodesmus*, *Coelastrum*, *Dictyosphaerium*, *Micractinium* and *Scenedesmus* all showed greater increases at Shadeville during the time of primary sedimentation in 1938, than while the trickling filter was operating in 1937, and continued their large numbers, although in lesser degree, in 1939, during activated sludge treatment. On the whole the plankton fail to show sharply the differences in the condition of the river during the three periods when the Columbus sewage was receiving three different types of treatment. It is known that some plankton, green and blue green algae, will thrive in raw sewage, but it has also been shown (26) that *Scenedesmus* will diminish and tend to die out in sewage after two or three days, probably because of the heavy bacterial growth. Such increases in phytoplankton as have been found are undoubted evidence of the decrease of organic matter and bacterial numbers. It is disappointing, however, that the three types of treatment of the Columbus sewage are not more clearly reflected in the behavior, quantity and quality of the Scioto plankton. It may be that too sudden changes have been expected, and that a river, despite floods, enormous sudden changes in silt content, organic loading, etc., is basically resistant, and changes slowly, and that its plankton inhabitants too, while bowing before these storms, change slowly.

THE VOLUME OF PLANKTON

As all living cells, or those that appeared to be living, were counted in this study, some rather imposing figures were obtained. Numbers of organisms per liter can very easily mount to huge figures in the case of very small organisms. Kofoid (27), counting the filter paper catch of *Cyclotella meneghiniana* in the Illinois found as many as 2,888 per ml. at one time, a number comparable to those found in the

Scioto, although four times this number have been recorded on several occasions.

Quite obviously some of the importance of these populations is dependent on the size of the individual cells. Kofoid found that when he encountered one cladoceran ("water flea") he encountered 86,000 algal cells and 18,000 protozoan cells; the whole population represented to him a more or less balanced biological assemblage. For the purposes of this survey, it has been found desirable to reduce these species populations to a comparable basis by estimating their volumes in parts per million. The protoplasmic bodies of these water dwelling forms are probably between 95 and 99 percent water. One determination made in the Cincinnati laboratory gave 2 percent as the dry weight of a mixed but relatively pure plankton population. For each of the more than 400 species encountered on this survey an average form has been selected: sphere, double cone, ellipse, etc., and enough Scioto River specimens measured to give average dimensions to each of the species. This permitted a computation of its size in cubic microns, and as 1,000,000 cubic microns per liter is equivalent to 1 part per million by volume, it is possible to express the population figures in parts per million by volume. If it is desired to express results in cubic standard units, as employed by Purdy (28), it is only necessary to multiply p. p. m. by 125 to obtain the number of cubic standard units. To those who find a large chance for error in such treatment, it can only be said that there seems to be no better way of comparing the relationships between say, 5,000 *Chrysococcus rufescens* and 2 *Euglena viridis* per ml.

The species encountered have also been classified as to whether they are holophytic, holozoic, or saprozoic in their nutrition. Such a classification presents many difficulties. Possession of chlorophyll—and this is true of the blue, olive green, brown, yellow, and red forms—tags an organism as holophytic. But many of the colored flagellates, as *Ochromonas* or various dinoflagellates, ingest solid food too. Also, these photosynthetic forms presumably liberate CO₂ during darkness.

Separation of the holozoic and saprozoic forms is largely based on many years of personal observation, but also on the works of Sandon (29) and von Brand (30). It is probably not as useful as the former distinction, and is also subject to exception; for example *Euglena agilis*, green, thrives on a dextrose-peptone solution, as well as in river water, but it also loses its color in some organic media, hence is either holophytic or saprophytic.

Using these distinctions, the organisms at each station on each sampling date were computed in parts per million by volume. The greatest holophytic population was 32,933 p. p. m. at Chillicothe on September 24, 1937; the highest holozoic was 16,040 p. p. m. at Kellenberger Bridge, January 20, 1938; and the highest saprozoic 2,127

p. p. m. at the same station on the same date. This means that at Chillicothe on September 24, 1937, the river contained over 3 percent of green cells by volume. Actually, at that time the water had a green color. These figures do not approach pure cultures; *Euglena agilis* in culture is often so dense a single drop is bright green.

The green cells usually make up the larger part of the catch, and their volumes are three to five times that of the colorless cells. The implied exceptions are in the low temperature ranges, 9.9° C. and below, and as illustrated in table XXXI (which is an average of the volume in parts per million of the three types of plankton at one of the river stations), the colorless cells are usually more abundant then. This table serves to show two other points about the volume distribution of the three plankton groups. One is the effect of temperature on the volume of plankton and the other the effect of volume of flow. Three temperature ranges were considered; 9.9° C. and below; 10.0° to 19.9° C.; and 20° C. plus. Table XXXII shows at what temperature and what flow range each of the 13 stations had its maximum (1), intermediate (2), and lowest (3), average volume of zoo- and phyto-plankton. There was no occurrence of the maximum volume of phytoplankton in the low temperature range until flood stages in the river, then the maximum occurred twice in the temperature range 9.9° C. and below. The phytoplankton maximum occurred only five times in the next temperature range, but at 20° C. or higher it occurred 50 times. This agrees with the warm weather and maximum light occurrence of green algae. Zooplankton maxima were 17 in the low temperature range, 13 in the middle and 28 in the high range. Both zooplankton and phytoplankton favored the low water stages. For distribution of this sort there are easily recognizable favorable factors; in addition to those mentioned for phytoplankton they are: age of water, clarity of water, greater constancy of environment and such. It does not follow that this concentration of plankton at low flow and high temperatures means that the stream is at its greatest oxidative rate, but it certainly has a high oxygen resource at such times, being frequently supersaturated with oxygen. At low flows there is probably a greater dependence on phytoplankton as a reoxygenating agent than at high flows. This is because the stream surface is smaller, temperatures tend to be higher (although extreme low flows have persisted until the end of December) there is less dilution, and there seems to be a somewhat greater volume of zooplankton. A close correlation is found at low flows, and temperatures above 10° C., between the oxygen content and the phytoplankton content, as can be seen by comparing figures 27 and 36. Notable discrepancies are the much greater fall of the former at Shadeville (due probably to the high B. O. D. of the entering sewage) and the pronounced drop below Circleville, also greater than the drop in phytoplankton. At low flows and

low temperatures, there is not a close correlation, and it is evident that factors other than phytoplankton (i. e. temperature) materially affect the oxygen content of the river. Below 10° C. there is a greater percent of dissolved oxygen in the lower river, despite the much smaller volume of phytoplankton, and a larger volume of zooplankton than between 10° and 20° C.

Table XXXI.—*The averaged volume, in p. p. m., of plankton at Commercial Point for 3 temperature and 5 flow ranges*

Flow range c. f. s.	Temperature range	Holophytic plankton	Holozoic plankton	Saprozoic plankton	No. samples
0-175.....	9.9° C. and below.....	81.6	366	16.0	1
	10.0-19.9° C.....	309.0	166	27.7	4
	20.0° C. and above.....	2,250.0	930	37.0	3
175-490.....	9.9° C. and below.....	270.0	955	150.0	12
	10.0-19.9° C.....	1,640.0	178	40.9	5
	20.0° C. and above.....	5,300.0	574	128.0	19
491-982.....	9.9° C. and below.....	175.0	259	109.0	5
	10.0-19.9° C.....	1,100.0	315	163.0	2
	20.0° C. and above.....	1,860.0	1,080	82.2	11
983-2800.....	9.9° C. and below.....	107.0	683	83.3	6
	10.0-19.9° C.....	86.9	239	31.6	5
	20.0° C. and above.....	1,700.0	722	121.0	11
2810+.....	9.9° C. and below.....	913.0	544	9.93	9
	10.0-19.9° C.....	40.4	362	1.80	1
	20.0° C. and above.....	3,480.0	1,350	159.0	3

Table XXXII.—Location of averaged maximum volumes of zooplankton and phytoplankton according to three temperature and five flow ranges. 1=highest volume in p. p. m. of plankton; 2=next highest; and 3=third highest. Note that in all but two cases, the maximum volume of phytoplankton was at 20° C. or above

Station.....	Columbus		Shadeville		Comstock Point		South Bloomfield		Red Bridge		Circleville		Peasbana bridge		Kellenberger		Chillicothe		Kilgore		Higby		Waverly		L. S. ville		Total		
	Z.	P.	Z.	P.	Z.	P.	Z.	P.	Z.	P.	Z.	P.	Z.	P.	Z.	P.	Z.	P.	Z.	P.	Z.	P.	Z.	P.	Z.	P.	Z.	P.	
Temperature Flow.																													
29° C. and below:																													
Lowest.....																													
Low.....	3	3			2		1		2		1						1	3	3	3							1	3	
Median.....	3																										4	1	
High.....			3										1													2	3	2	3
Highest.....					3								2							3	1						1	4	
10.0-19.9° C.:																													
Lowest.....			2																								0	1	
Low.....	2	2																									1	4	
Median.....					3		2	3	2		3	1	3	2	3	3		1	1	2		2	2	2	2	3	2	1	
High.....																											1	4	
Highest.....																											0	1	
20.0° C. and above:																													
Lowest.....	1	1	1					1		1	1	3			1												1	3	
Low.....																											3	7	
Median.....								1	2		2		2	2	3	2	3	1	3	1				1		1	1	4	
High.....																											1	4	
Highest.....					1							2	1		1								1				0	2	

PLANKTON VOLUME RELATIVE TO RIVER CONDITIONS

Finally, it may be asked if the sanitary condition of the river is closely reflected in the volume of all phyto- and all zoo-plankton. The answer is a decided negative. Figures 35 and 36 show the distribution of the zooplankton and phytoplankton at low flows from Columbus to Lucasville, the volume being averaged for each of the three temperature ranges. At low flows and low temperatures there is actually more zooplankton in the lower river where the B. O. D. and total bacteria counts are low and where the D. O. is high, than in the polluted stretch at and below Shadeville. At the middle and high temperature ranges the zooplankton volume follows an erratic distribution curve, and the phytoplankton volume increases sharply according to temperature, but not according to pollution.

Almost the same relationships hold for the middle flow range, but there is a noticeably larger phytoplankton volume in the lower river. In this respect, however, the phytoplankton is merely following a trend apparent in all carefully examined rivers, and departs from that trend only in not showing a decrease in the lower end of the river.

DISCUSSION

Because the B. O. D. decreases downstream, the D. O. rises, and the total bacteria and coliforms decrease in the cleaner reaches, it seems as if only the larger biological agents fail to indicate the sanitary condition of the water. Actually this is far from the case. It has been found and demonstrated for the Scioto that some of the plankton forms strongly prefer foul water; others exhibit as great a preference for clean water; and a limited number of species of each type are readily recognized and their presence in larger numbers is a categorical classification of the type of water where they were taken. The studies of the plankton have not been highly successful in showing floral and faunal differences according to whether the river was getting a relatively large volume of effluent from an overloaded trickling filter, or treatment by primary sedimentation alone, or complete treatment by the activated sludge process. This had been hoped for, because at low water Columbus uses most of the river flow, and if the effluents during the three types of treatment were markedly different those differences should have been apparent. Biologically indicated differences were small.

The study has given some very good results in other ways. It has undeniably shown that some entire groups of organisms cannot be used as indicative of the sanitary condition of water, but that individual species must be considered in this respect.

It also appears that there are certain forms highly characteristic of running water, almost, if not actually comprising an ecologic

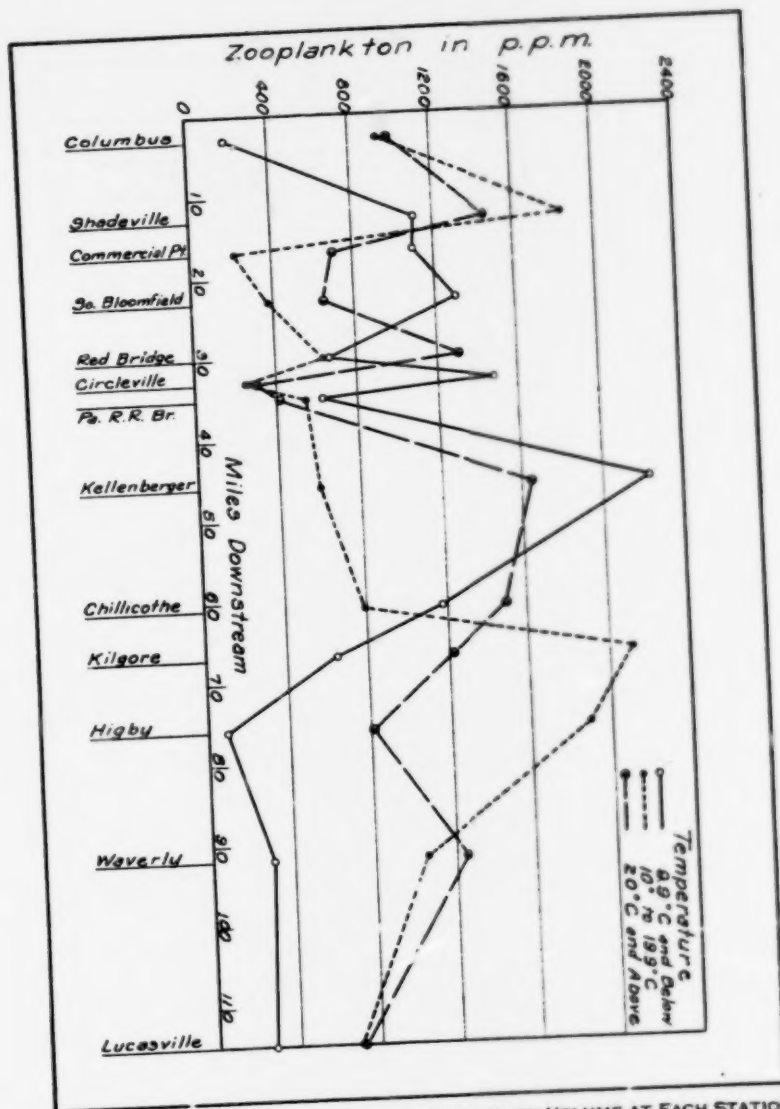


FIGURE 35. ZOOPLANKTON IN PARTS PER MILLION BY VOLUME AT EACH STATION DURING THE LOW FLOWS FOR THE THREE TEMPERATURE RANGES.

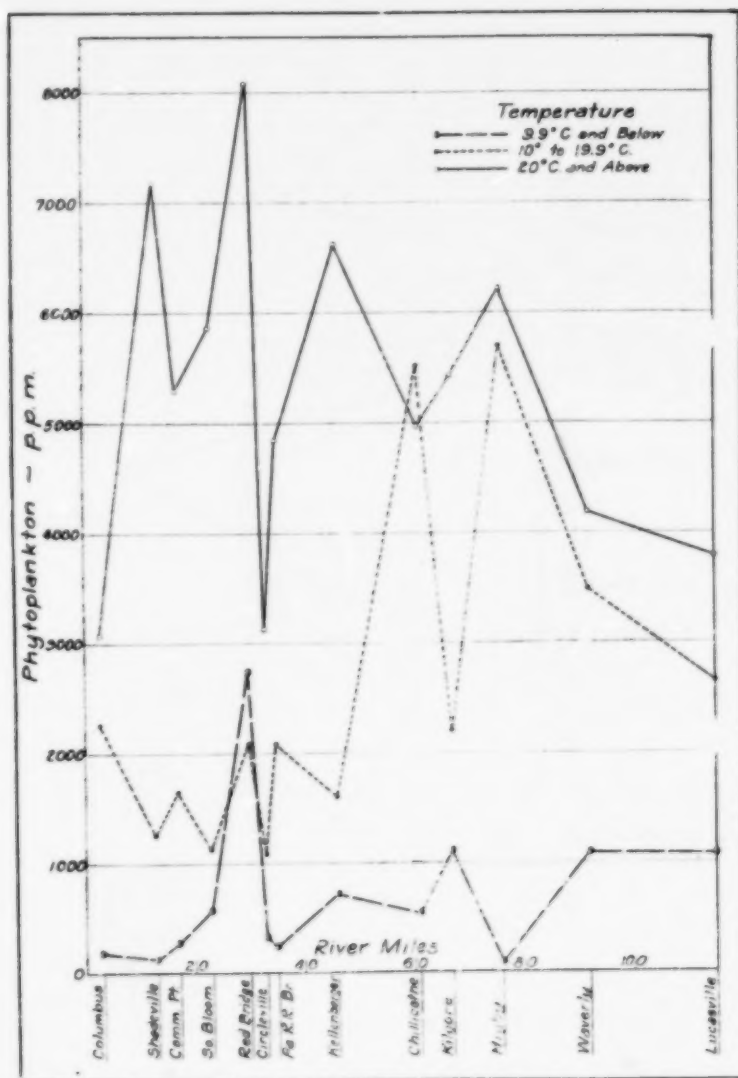


FIGURE 36. PHYTOPLANKTON IN PARTS PER MILLION BY VOLUME AT EACH STATION DURING LOW FLOWS FOR THE THREE TEMPERATURE RANGES.

group. The species list is a long one, and the numbers and volume of the plankton far in excess of those reported for hitherto studied streams, but some forms have been found in the running waters of streams more consistently than in other situations.

As usual with such studies, some questions have been answered but many more have arisen to replace them. The Scioto is a hard water river, not canalized, with a fairly rapid run off (the slope from Columbus to the mouth is about 1.6 feet per mile), low in nitrates and probably low in phosphates, except from the Columbus sewage, yet has a larger plankton population than heretofore known from any river. It is, biologically, a highly productive river—but does its large population come from the fertilizing effect of the Columbus sewage? And if so, what is the nature of these fertilizing substances? And how far down the river do they persist? Large plankton populations have been found within a few miles—5 to 15—of the headwaters of some of the tributaries. Much of this data is not germane to the present study, but a partial answer has been obtained to some of the questions which were asked, and some progress has been made with regard to others.

STUDIES OF BOTTOM ORGANISMS AND SEDIMENTS

THE CHARACTER OF A STREAM, ITS CHANNEL AND SEDIMENTS

The channel through which the stream flows should be examined in the many-sided problem of a sanitary survey. The stream bottom, in particular, seems to offer valuable information.

The carrying power of water for suspended matter such as silt, increases marvelously with any increase in the speed of current, and, by the same token, decreases very rapidly in case current speed lessens. Thus a riffle shows stones or pebbles that are nearly or quite clean of mud, even after silt-laden flood water has prevailed, but lessened velocity in the pool below has resulted in a bottom deposit of silt from this same water. Successive floods add to the deposited material, and the pool, where current is slack, tends to fill up with matter which formerly was suspended in the water and was carried along by the speed of the current. Thus the bottom is in effect a depository of the suspended matter in such water as has already passed. The bottom sediments are an accumulation of settleable solids that formerly constituted a part of the water. A pint of such sediment may be the accumulated solids component of a thousand gallons, more or less, of slow-flowing water overhead.

Physical factors.—Water in motion will erode banks and channels. The outstanding results of such motion, the profound canyon, the extensive and fertile flood plain, the changed course of a river, have received much more consideration than has the basic fact responsible for these great changes. Instead of every stream being a law unto itself, the stream is actually in a sort of bondage to the set-up imposed upon it by the degree of slope of its channel, the composition of its bed and sides, and the amount of water drained from its watershed and demanding removal. Velocity of current, meantime, is a sort of referee impartially deciding not only the amount of erosion but also the quantity of deposition. The mighty canyon and the small gully, the thousand acre flood-plain, and the delta at the stream's mouth, all are legitimate products of this controlling set-up.

The normal stream-flow, eroding where current is swift, but depositing portions of this suspended matter when the current slackens speed, results in a channel on whose pool bottoms there exists a nice condition of balance where the least disturbance of the bottom water will send a mass of the scarcely settled fine sediment into suspension again in the surrounding water. Thus the flip of a fish's tail will roil up the

water and obscure the fish, and a crawfish scooting backward is speedily lost to his pursuer. Even a minor increase in stream velocity may disturb quantities of bottom material sufficient to produce a heavy turbidity.

Rapid succession of irregularities in channel, sharp curves, rock ledges, boulders in the stream bed, deep pools, islands—all these tend to produce effects in the stream velocity with consequent variations of the amount and kind of deposition of suspended matter on the stream bottom. The average stream consists of a bundle of varying situations with respect to erosion, to character of channel, and to bottom deposits as well, and all suspended matter must run the gamut of such of these factors as, to a greater or less degree, affects the process we call sedimentation.

Weather conditions may affect bottom sediments profoundly. Heavy rainfalls with consequent high water means increased velocity of current that will not only prevent deposition of any but the heavier suspended matter, but will, in addition, disturb and remove all but the most stable of the bottom sediments already deposited. Should such scourings occur quite frequently throughout the year there will be too little time for the undisturbed maturing of a crop of representative fauna, except those kinds that are able to weather the frequent high-water disturbances, and even these may be swept out by the force of an unusual flood. That this latter is a very real factor is shown by the observations of Needham (31) on Six Mile Creek in 1927. A drift net was run for 15 minutes in the swift flood waters, in order to ascertain the effects of high waters on such bottom organisms as were of known importance in the food of trout. The resulting 15-minute catch showed practically every kind of aquatic organism which had been collected from this stream during the previous summer. The great majority were dead, or were badly injured by the violence of the flood waters.

In addition to the material suspended in the water, vast quantities of sand, pebbles, and even large boulders are rolled along the stream bottom, constituting a natural pebble grinding mill which grinds, crushes, and disintegrates the heavier bottom materials as witnessed by the rounded nature of the pebbles and boulders of the stream bed.

Sources of sediments.—It is fully recognized that suspended matter may be "inorganic" or "organic"—that is, it may be lacking in putrescible or organic matter, either living or dead, and consist entirely of stable mineral matter. Such suspended matter is inorganic. Organic suspended matter on the other hand is made up chiefly of matter (a) in the living condition, such as spores, microscopic plants, and animals or their dormant stages (cysts, eggs, spores, and the like), or (b) the disintegrating (and usually putrescible) re-

mains of once-living matter, such as lifeless organisms of the types mentioned above, or minute fragments of larger forms, such as molts from crustacea, legs, feet, wing, antennae, scales, hairs, etc., from disintegrating organisms, plant remains in great variety, leaf and stem fragments, spiral vessels, fibers, chaffy seed-coverings, rootlets, and the like.

Drainage from areas fertilized by manure may yield chaffy seed-coats or undigested fragments of oats or corn. Sewage-polluted waters may contribute seeds of tomato or grape, fibers from celery, orange, and paper, or other fecal remains.

These visible objects constitute in general the remains of organisms that were once in the active living condition. Between that first condition, when each organism was doing work, and this final end-product stage, there has intervened a period of change which is vastly important in a consideration of the sanitary status of the water. We refer to the processes of disintegration, decomposition, putrefaction, and oxidation by means of which the relatively immense mass of protoplasm (constituting the bodies of the former living organisms) has been released into the water.

Most organisms on dying, sink to the bottom. At certain stages of putrefaction and gas formation, the lighter ones are buoyed up. Necessarily, however, many of the dead organisms undergo much of their putrefactive changes on the bottom, the bottom sediments are thus increased, and the content of organic and putrescible matter is likewise increased.

A source of much suspended matter is the "dust" of the atmosphere. Only those who have made actual examinations of the water are aware of the presence there of a varied assortment of wind-borne spores, pollen grains, and pollen masses; tiny fragments of various kinds that are light enough to be carried by air currents; scales from the wings of insects, particularly butterflies; fibers and delicate parts from the parachute apparatus of air-borne seeds such as wild lettuce, milkweed, dandelion, cat-tail, and a host of others. Pollen from pine trees was frequently found by us in the plankton catches collected in California rice fields. This pollen, air-borne, had probably originated in mountain forests, 30 miles away, or perhaps had even floated downstream the 90 miles from the upper Sacramento River—into the river-fed irrigation ditch, and thus to the rice fields. In our Central States, a very common object in plankton catches is the pollen of rag-weed.

Even in the upper air-currents far from cultivated areas and from forests, Meier and Lindbergh (32) found numerous objects in the atmosphere. Exposing petrolatum-coated glass slides at elevations of 3,000 to 8,000 feet above Greenland, spores of fungi, pollen grains, unicellular algae, diatoms, volcanic ash, and other objects were trapped on the slides and were reported by these investigators.

Changes in character of a stream due to the advent of man.—In a natural stream, prior to the advent of man, there will be seasons of flood during which the water will be turbid because of eroded banks or bottom. Such silt-laden water escaping over low banks deposits repeated layers of mud on adjoining areas, thus building up flood-plains. Deposited in the stream channel as velocity decreases, this bottom mud introduces nothing new in the sanitary status of the water, for it is merely such natural material as has been eroded farther up and is essentially a part of this natural stream.

Passage of a stream, especially during flood stages, through and over wooded areas necessarily brings into the waters a vast accumulation of leaves, stems, fragments of wood, bark, rootlets, etc., much of which is not seen by the average observer on account of the high turbidity of the water. The resulting bottom is a somewhat loose aggregation of sediment, plant fragments, and decaying leaves, these latter frequently producing a disagreeable odor.

Practically all of the plant detritus shows varying degrees of decomposition, completely skeletonized leaves, the "veins" and minute, net-like framework only (all of the softer protoplasm formerly containing chlorophyll having decomposed), worm-eaten bark fragments, and rotted wood. There is also comparatively fresh plant material of these and various other kinds. The whole assortment will eventually decompose slowly and remain meantime in the bottom sediments. It is, after a fashion, an aquatic compost doing its bit to increase the volume and the variety of the bottom sediments.

After the advent of man, if the natural stream referred to is subjected to the events that occur when civilization (at least the advent of man) becomes a factor, certain changes usually affect the stream, somewhat as follows:

1. Removal of adjacent woodlands, more rapid melting of winter snows, higher floods.
2. Cultivation of cleared lands, drainage of tilled soil areas, probable increase in turbidity, and unquestioned increase in dissolved organic matter in water.
3. Industrial wastes from sawmills, coal mines, paper mills, tanneries, dairies, slaughter houses or stockyards, steel mills, creosote factories, breweries and distilleries, dye works, beet sugar works, gas and coke producing plants, and a variety of others. Each contributor hopes only to get rid of his own wastes without regard to downstream water users.
4. Sewage, frequently untreated, from increasing populations in towns and cities. The spring thaw releases into drainage streams the frozen accumulation of numerous outdoor toilets.

It is reasonably safe to say that all of the wastes mentioned affect the quality of the water, some of them seriously, while all except the first particularly affect the quality of the bottom sediments. For example, Moore (33) calls attention to the special hazards of gas works

wastes which are highly toxic to fish and eventually form a gummy coating on the stream bottom.

Erosion silt deposited as sediment adds no special sanitary hazard. There follows no marked evidence of decomposition. There is no odor except a "clean earthy smell" for such sediment is highly inorganic. But the bottom environment is thereby altered somewhat, as shown by Ellis (34). Light is screened out, the rate of heat radiation being changed thereby, and stream bottoms are blanketed, retaining there any deposited organic material.

When sewage is discharged into a stream a portion of sewage settles out, and comes to rest on the bottom in those places where the velocity of the moving water is low. Unless swept out by a sudden flood, these sediments continue to accumulate and a "sludge-bank" is thus formed, representing uncounted thousands of gallons of sewage which formerly contaminated the stream. Thus this sedimented matter provides a reasonable measure of the essential sanitary status of such water as made up the stream at that point. Some hours later, and several miles farther down, this same stream, again flowing slowly, will unload some remaining suspended matter that has been in the water longer, and is, therefore, more completely decomposed, contains less organic matter and is relatively free from any danger of septic nuisance although it may continue to be a physical nuisance by obstructing the channel.

Studies in the Illinois River (35) show that the heavy demands on oxygen by sludge deposits between Peoria and Havana produced a serious condition of unbalance, the chemical balance-sheet showing "in the red" chiefly by an estimated 263,000 pounds of oxygen per day required for the B. O. D. situation due to these sludge-banks in a 42-mile stretch of river immediately below Peoria. This was during the critical, low-water period of July and August. The total B. O. D. exerted daily was 526,000 pounds and of this required amount, 263,000 pounds (50 percent) was estimated to be due to the deposited sludge.

Further data relative to the sludge problem are recorded by Eddy (36) substantially as follows:

(a) When sewage is discharged into a water course it ordinarily separates into two parts—that which is heavy enough to settle and form a sludge deposit, and the remainder, which is in solution, or is finely enough divided to be carried along by this current.

(b) There are also in this sewage, colloidal and dissolved organic matters. These are more or less putrescible. Of total impurities in sewage 20 per cent may be solids which will settle in quiescent water. These solids may amount to 50 pounds of dry solids per capita per year. For a population of 1,500,000, this amounts to 37,500 tons—approximately 200,000 cubic yards. Such amounts may change moderately deep water into shallow flats. As much as 65 percent of this deposited matter may be decomposable.

(c) Forthwith the living mill begins to grind and the organic matter is gradually converted into stable mineral substances. Dissolved oxygen is con-

sumed in the process * * * if dissolved oxygen does not reach zero, putrefaction will not take place and obnoxious odors will not be developed.

(d) In many cases the portion of the polluting water which is most important is that which consists of living organisms, first because of the danger of infection of public water supplies by the pathogenic bacteria and secondly because of the important part certain nonpathogenic organisms play. Through their life processes they transfer the complex dead organic matter into simpler forms, some of which constitute food for minute plants and animals, which in turn nourish larger forms such as fish, a food for man. This is, in part, the so-called self-purification of the stream.

(e) The organic matter in the sludge deposits undergoes changes somewhat similar to those that take place in the flowing load of impurities. Sludge exerts an oxygen demand in the same way and subject to the same limitations as the flowing load. Settleable solids are deposited at all seasons, in cold weather decomposing very slowly. Thus, in northern latitudes, there is an accumulation of potential oxygen demand, and during the warm season the oxygen demand of this partly decomposed material is added to that exerted by the deposits formed in that season.

Significance of the bottom sediments.—The veteran biologist, Professor S. A. Forbes, in 1913 (37) called attention to the fact that the bottom sediments bore testimony as to the character of the water from which it had sedimented and of which it previously formed a part as the "suspended matter." "The sediment is an accumulation of evidence," he said, as he noted the physical characteristics, the odor, and the population consisting of molluscs, of insect larvae, or of worms, that found agreeable environment in these sediments. He further pointed out that there was some degree of agreement as to the sanitary status of the stream, in the evidence furnished (1) by physical inspection, (2) by chemical examination, (3) by prevalent plankton organisms of the water, and (4) by physical and chemical conditions of the bottom sediments, together with their characteristic organism content. The classic paper referred to is notable for the oft-repeated four-part analysis of the polluted Illinois River, at various points, and for the conservative but definite conclusions based on the generally agreeing testimony furnished by these four witnesses.

Later work on the same stream by these investigators, and finally by the junior author, R. E. Richardson, without exception included due attention to the bottom conditions and the bottom organisms. No stream in this country, perhaps no stream in existence, has received such thorough and repeated study of its bottom conditions and organisms as has the sewage-polluted Illinois River, in the several excellent publications by Forbes and Richardson.

It is to be regretted that, in many stream examinations, bottom conditions have been nearly or quite ignored. Men have thought, naturally perhaps, that the water itself was the only thing of importance. Much attention was given to the source of water, and to the general condition of the watershed. Prevalent opinion was gradually changed when, after many experiences with high water and flood con-

ditions, it became apparent to observing students that bottom conditions constituted a very real factor, that this bottom in fact, functions as a small but *continuous* watershed, and that originally clean water, flowing under flood conditions over a polluted stream bottom is quite as likely to suffer contamination as is clean rain water collected from a thousand-acre watershed consisting chiefly of fertilized fields or of pastures where large numbers of hogs and other live stock wade at will in the tributary brooks. It was realized that an apparently clean stream which harbored frequent bottom accumulations of soft mud, or trash of any sort, will at flood time dislodge much of this accumulation, and it would then temporarily be a part of the "water." If the mud be clean, well and good—but if not, trouble might result to water users.

From the biological point of view also the suspended matter is quite capable of producing a series of results with regard to the water, some of them beneficial, others questionable, or even harmful—depending on the intended use of this water. Silt in suspension obstructs the passage of sunlight into the water and thus hinders or stops the important biological activity, photosynthesis, which provides large amounts of oxygen, much needed sometimes in a polluted stream. This same silt, on settling to the bottom, often carries with it certain organisms or the plankton whose normal activities in the water tend to maintain a much-needed condition of biological balance. Certain small crustacea in particular become weighted with silt on their numerous appendages, and are thus removed from the upper waters, where these crustacea would normally operate to prevent an overpopulation of minute algae, some of which, when present in uncontrolled numbers, cause serious trouble by producing tastes and odors in the water.

The bottom of a stream constitutes favorable environments for a variety of organisms—crawfish, insect larvae, beetles, and "worms" familiar to every boy (or man) who has waded the shallow stream and overturned the bottom stones in search of bait or perhaps for other reasons. The advent of a sawmill, paper mill, or other industrial plant introduces marked changes in bottom conditions, which may also bring about distinct changes in the bottom population, or may even kill off practically all organisms in both water and bottom and leave the stream an aquatic desert. An aquatic environment, apparently favorable, may in reality be barren because of the destruction of fish food and small animal life which are vital to the existence of the fish. It is, says Claassen (38), like a newly burned-over prairie or pasture field in which grazing animals are expected to find their food, but the food is absent.

Various investigations have served to demonstrate that, in general, bottom conditions in a stream constitute a source of valuable informa-

tion, particularly if the stream is to be utilized mainly for some specific purpose such as domestic water supply, or such industrial uses as commercial laundry purposes, pulp mills, for paper manufacture, and other industries requiring a water whose turbidity is not excessive in amount, nor of long duration at any time. Bottom deposits of mud and silt, reintroduced into the current at times of high water, will greatly reduce the value of such water for the industrial purposes mentioned.

If the water be needed for domestic use, any bottom deposit, if rewashed into the stream, is capable of producing trouble, particularly if such deposit is caused by sewage pollution farther upstream. These "sludge banks" constitute one of the chief difficulties encountered by waterworks men and, indirectly, by municipal health authorities as they produce tastes and odors difficult and expensive to remove and have been suspected as the cause of epidemics of diarrhea when flushed out by rising water. The study of the stream bottom thus becomes a matter of no small importance in order that the health hazard, if present, may be properly appraised and removed or otherwise avoided.

Outstanding studies of bottom sediments.—The extensive work on the Illinois River by Richardson, part of it under the direction of the veteran biologist of honored memory—Dr. Stephen A. Forbes—easily takes first place in the studies of stream bottom conditions in the United States. These studies, chiefly during the interval 1900 to 1925, occupied most of Richardson's time. Moreover, he obtained his exact information relative to the Illinois River by his own personal work and observations, much of the time being spent on the river itself, in a floating laboratory. Richardson's statements, therefore, have the great advantage and background of extensive first-hand acquaintance with the many interrelated factors concerned in a typical sewage-polluted stream.

A late work by Richardson (39) summarizes much of the findings from his studies. Frequent reference to this classic paper will be made in this present paper relative to the Scioto River.

After listing some 27 kinds of bottom organisms rather definitely associated with presence of pollution Richardson says: "The number of bottom forms having dependable index value is surprisingly small, and even these must be used with caution" * * * "Of the 27 kinds * * * only two, *Limnodrilus hoffmeisteri* and *Chironomus plumosus* were generally common enough over wide ranges to warrant confidence in their value as indicators when taken by themselves."

Again, as well stated by the same writer—"Interpretation of degrees of abundance is most likely a wholly relative matter. Tubificid totals per square yard varied from 1,000 to 350,000 in certain territory with-

out our having any reason for supposing conditions better at the one collecting place than at the other."

Richardson's chief concern is for such sanitary appraisal of the bottom organisms as is adequate and just—but not over stated meantime. Justice, and conservatism as well, are further expressed in his statement that "sometimes absence, or reduced numbers of formerly-present clean-water species in a given area may be as important as presence now of known polluttional forms in determining the extent of recent pollution." Such a statement carries all the more weight when it is recalled that it was Richardson's study (40) that demonstrated in 1921 that not only by abundance of certain polluttional forms formerly scarce, but also by scarcity and killing out of cleaner organisms formerly abundant, there was unmistakably indicated the downstream encroachment of the "pollution zone" due to Chicago sewage at the rate of 16 miles per year for the preceding 5 years.

Richardson (39) further cites (page 470) a striking example of the change wrought by increased pollution on certain of the cleaner bottom forms—and also on such polluttional forms as might be present during a period of five years, as follows:

	Numbers per sq. yd.	
	In 1915	In 1920
I. Cleaner forms:		
Sphaeriidae	1,709	46
Snails	496	20
II. Polluttional forms:		
Sludge worms	16	2,463
Midge larvae	10	733

Relatively clean streams were studied by Percival and Whitehead (41) (42) to ascertain the types of invertebrate fauna present.

It is significant that they report, in essence:

1. Streams were well stocked with fish. Trout and grayling are mentioned.
2. The D. O. content was high.
3. At least 3 of the streams had stony bottoms.
4. The great majority of organisms (chiefly bottom fauna) were those requiring water well charged with oxygen.
5. Insect larvae in general were abundant (May flies, Stone flies, Caddis and Chironomids).
6. Tubificid worms were absent from 5 out of 7 types of environment, sparingly present in two types.

The above summary is in striking contrast to the findings of Ludwig in his study of a polluted stream, as given in the following data.

In Ludwig's study (43) of the Hocking River, a polluted stream, undertaken to obtain data as to the effects of domestic pollution, the results obtained applied in part to the types of bottom organisms capable of living in a sewage-polluted stream. Results applied also to the nature of the bottom itself, this being relatively clean mud, silt, and sand above the pollution, and "black muck and organic

debris, with a foul privy odor" below the pollution. In the clean section the dominant bottom organisms were insect larvae, whereas in the polluted areas sludge worms were very heavily predominant, numbering over 300,000 per square meter. The use of such a polluted stream for domestic water supply would be highly undesirable, not only because of the condition of the water itself, but also because of the hazard of wholesale repollution of the water should flood conditions stir up the vile bottom sediments. Ludwig's study illustrates the value of knowing the facts, whether pleasing or not, in regard to the condition of a stream.

Our own study (44) of the Illinois River in 1921-22 included examination of over 200 samples of the bottom sediments collected monthly at selected stations over 267 miles of the stream and representing every season of the year. The more important findings were as follows:

1. Sediments from the upper sewage-polluted sections of the river had a strong unpleasant odor. Organisms in these sediments consisted chiefly of tubificid worms, which were very numerous, averaging over 2,000 per liter of mud. Certain sewage-tolerant organisms (*Sphaeriidae* and larvae of *Chironomids*) were moderately abundant. Such forms as are normally found in the odorless sediments of cleaner streams populated by fish were practically absent.

2. Sediments from the lower reaches of the river, apparently a clean stream were without special odor. Organisms in these sediments showed a large variety and relative abundance of the gill-breathing insect larvae (May flies, caddis flies, etc.) and similar forms normally found in the cleaner streams. The pollutional tubificid worms dropped to an average of 13 per liter of mud.

Farrell (45) studying a polluted stream voices his belief that "a determination of the bottom fauna often gives a more exact index of the extent of pollution than does a chemical analysis which may have been taken during a period of either high or low outflow of polluting substances. * * * These bottom inhabitants give a more accurate picture of the unfavorable conditions which exist all year round than any other analysis." Farrell further calls attention to the frequent finding of inconsistent high oxygen values even in polluted waters because of the proximity of riffles, falls, and overflow from dams, whereas the bottom fauna in these same areas consistently showed that pollution was present.

Similar opinion is stated by Emmeline Moore (31), page 14, essentially as follows: "The biologist * * * adds most impressively to the data supplied by the chemist. This is especially true because of the greater stability and permanence of conditions at the bottom. The deposits of foul sludges and their accompanying foul water organisms are thus a fruitful * * * aspect of the study of existing conditions."

Sludge worms.—In bottom samples from a polluted stream it is desired to learn the approximate abundance of the sludge worms, be-

cause of the apparent significance of this worm and its activity. Half or two-thirds of its body is underground, and the worm slowly tunnels about, undermining and ingesting the soft bottom mud. The anal end of the worm, projecting an inch, more or less up into the water, waves about rhythmically in the process of breathing. On the assumption that this activity is a matter of considerable importance, any data offered should be based on facts relative to the habits of the worm. In this connection the technique of obtaining the bottom sample, together with the amount of sample, are important.

One of the most outstanding characteristics of sludge worms is their tendency to occur in groups, or patches. In a sewage-polluted stream such as the Scioto River most of these sludge-worm groups which are visible in the shallow water are near the edge of the stream. Such groups can also be seen with difficulty in the deeper water—and bottom samples obtained from such deeper water furnish evidence of their presence. In the writer's experience collections have been made from depths varying from 1 or 2 inches up to 35 feet. But it is only at the slight depths, and in clear water, that the groups and colonies may be *seen* to advantage. In the scores of observations made during a period of over 25 years, these worms have never been found uniformly distributed in the bottom mud—but *always in groups*, large or small, some containing only a few scores of worms, other large groups estimated to contain several thousand. Weston and Turner (46) thus comment on this same matter: "The worms appear on the muddy bottom in colonies as red patches which vary from 3 to 12 inches in diameter and contain countless individuals."

Distance between these groups varies greatly—from 5 or 6 inches to as many feet. It seems probable, to say the least, that in the deeper water, where one is unable to see the groups, the worms nevertheless occur mainly in this manner. Some evidence on this matter will be given later in this paper.

Apparently the method for proper sampling of these sediments which contain spots of worms consists in taking an increased number of samples, and then averaging the counts. This is, in effect, compositing the samples to some degree. This average will greatly lessen the probability of significant error as to the actual bottom population of worms, for it is extremely unlikely that the scoop or dredge will encounter the same square foot—or square yard—of bottom each successive time. In a prolonged study extending over a year or two, the relatively large number of single hauls (samples) taken on successive months will answer essentially the same purpose as would three or four hauls composited at each visit in a short intensive study. The visible group or colony of which we speak is an array of waving tails. Color of the worm is reddish, like that of an earthworm. A group the size of

one's hand is easily visible in shallow clear water, even if the observer is 20 feet distant.

The apparent importance of this worm as an indicator of the presence of pollution makes it all the more necessary that the bottom samples show, as accurately as possible, the real situation as to the relative numbers of worms occurring in that particular sampling place. The usual small dredge or scoop employed to secure a bottom sample by cutting out a fixed area is likely (1) to encounter bottom *between* these groups, (2) to enclose a small group, or (3) a large one, or none at all. Two samples taken at the same time and place, are thus likely to yield widely different counts of worms. The only possible remedy is to reduce this probable inaccuracy by taking two or more samples, at any given time and place (if a small dredge is used) and compositing these samples before making the count.

A sampling apparatus of the mushroom-scoop type, shown in figure 15, hauled along on the bottom 8 or 10 feet in taking a sample (the recommended procedure) is almost certain to encounter one or more groups of worms if these are present, and will also include mud from the between-groups area. It is thus reasonably representative—but is qualitative only. A quantitative sample, as taken in the exact area enclosed by the jaws of a cutting mud-scoop, such as that devised by Ekmann, undoubtedly has many advantages that greatly simplify computation of fish food available in a given area, providing the quantitative sample thus secured is truly representative of average conditions. To accomplish this latter a small sampler of the Ekmann type must necessarily be lowered several times, and the catches composited. Only then can we be reasonably certain that, so far as sludge worms are concerned, we are taking adequate precautions to minimize or avoid the gross inaccuracies and misrepresentations extremely probable if the count is based on a single sample, and involving an organism which occurs in scattered groups rather than being uniformly distributed in the unseen bottom mud.

Other bottom forms and their apparent reaction relative to sewage pollution.—Chironomid larvae apparently are second only to the sludge worms in a polluted stream, but their presence must be interpreted with care. There are many species, and, as might be expected, they tolerate to different degrees, the presence of sewage pollution. Richardson (40) lists only three as pollutational or tolerant. These are *Chironomus plumosus* L., *C. maturus* Joh., and *C. frequens* Joh. He lists as tolerant or indifferent the four species *C. decorus* Joh., *C. crassicaudatus* Mall., *C. lobiferus* Say and *C. viridicollis* and adds *Tanytus dyari* Coq. to this list. Then, indicating cleaner water, or of doubtful position, Richardson further lists six additional chironomids, and seven varieties from closely-related groups. In brief,

Richardson regards the chironomids as rather severely limited in their value as indicators of the presence of sewage pollution. Similarly Malloch (47) an authority on the subject of Chironomids, expresses his belief that these larvae as a group are much more abundant in relatively clean water than in a foul environment. Personally, the writer has found them abundant in the unpolluted water of ricefields in Arkansas and California but cannot vouch for the particular species. They may have belonged to the long list given by Richardson as indifferent to pollution, or to those listed as doubtful. Meantime it may be well to remember that any field capable of producing rice is fairly rich in organic matter, though this is not in the form of sewage.

On the other hand Weston and Turner (46) comment on the apparent scavenger habits of *Chironomus decorus*, "greedily devouring all sorts of detritus," and always to be found in large numbers in that section of the Coweeseet stream which was heavily polluted by sewage effluent. Their conclusion, in effect, was that *C. decorus* was abundant because of its favorable response to heavy pollution by sewage effluent. Richardson lists this same organism as tolerant or indifferent.

In Richardson's study (40) of the Illinois River in 1915 and 1920, he noted that most of the mollusks abundant at a given point in 1915 had disappeared in 1920. Specifically, out of sixteen species formerly present twelve had been killed out, in 1920, by the increasing load of Chicago sewage.

As with other organisms, the mollusks also differ in respect to their tolerance of sewage conditions. Some are water-breathers, obtaining their supply of oxygen from that which is dissolved in water. In case of long-continued and severe sewage pollution this oxygen supply may be entirely exhausted. Such snails or other mollusks as are dependent on this supply will quickly succumb. But other mollusks are air-breathers, and these secure their oxygen by coming to the surface for air. These are relatively indifferent to the amount of water-dissolved oxygen, hence can survive sewage pollution and attendant oxygen depletion much longer than can the water-breathing group. This fact was demonstrated by Baker (48) who found that water-breathing snails (*Musculium* and *Bythinia*) succumbed in five years to the increasing sewage pollution in Big Vermilion River but the air-breathers *Physa*, *Planorbis*, and *Galba* were able to survive for 8 years.

Weston and Turner (46) comment on the great increase in snails below the point of pollution. While they found only an occasional specimen (*Campelema*) in the nonpolluted stream above the outfall of the sewage effluent, they found very large numbers *below* this outfall. "The aquatic plants near Station 3A were covered with them * * *

1 day * * * 50 specimens were gathered by one scoop of the two hands." They report *Planorbis trivolvis* as the most common but *Physa* and *Segmentina* were also abundant. Now since both *Planorbis* and *Physa* are air-breathers, it might be that they were abundant because of the algae in and on which they find their food, rather than because of the sewage pollution. However, it is also to be remembered that the algae (and especially the slimy growth of protozoa, diatoms, etc., upon the algae, forming much of the food of snails) are in themselves a very frequent result of sewage pollution. In 1921-22 the writer (44) found large numbers of snails, chiefly *Planorbis*, in and on the great masses of green algae * * * (*Cladophora*) in the lower Des Plaines River at Lockport, Illinois, this river having been polluted some miles upstream by the sewage of Maywood, a suburb of Chicago. Thus in this case sewage pollution was still one of the causes, and perhaps the main one, that resulted in the great content of snails at a point sufficiently distant below the place of pollution to permit a partial recovery of the stream. It was thus an indirect and distant effect of the original upstream pollution.

Claassen (38), discussing methods of evaluating the fitness of a stream for fish life and absence of excessive pollution (in effect, the normal condition of a stream), mentions (1) superficial observation on the condition of the stream, (2) chemical analysis of the water, (3) minnow tests, and (4) examination of the stream for the presence or absence of biological indicators. Of these, the final one, No. 4, alone is relatively free from serious limitations and inaccuracies inherent in the other methods. Claassen says, in effect: Method No. 1 is subject to gross error. Mere visible discoloration may be harmless, but presence of actual poisons may be quite invisible. Method No. 2 has severe limitations in that it tells us the condition of the water only at the *moment of examination*, and nothing about conditions a month previous, nor the probable fitness for fish life a month hence. Method No. 3 also has limitations in that minnows surviving for 5 or 6 hours is not sufficient indication that fish life placed permanently in this same water will be similarly fortunate. Method No. 4, a study of the plants and animals which inhabit the stream, is the most reliable. Any stream capable of maintaining fish life must also maintain other living organisms (such as insect larvae), these forming the normal food supply of the fish. The algae and smaller organisms present in turn furnish food for the insect larvae. Presence of these various organisms in a stream indicates not only the condition of the stream at the time of examination, but tells us also that the stream has been fit to propagate these items of fish food during such a period of weeks or months preceding the time of study as was necessary for these insect forms to develop.

THE SCIOTO RIVER STUDY

Sampling.—If sediment be required, the collections obviously must be made at such points in the stream as may furnish this material, which is derived from the water passing overhead. Because the carrying power of water is a direct function of the velocity, a deposit of suspended settleable matter is possible only at such points in the stream as show decreased speed. Change in speed is, in turn, usually dependent on area of the cross section of available channel for the flowing water. Increase of this cross section, whether by depths or by width of channel, checks speed, and deposition of suspended matter takes place at this point. If the cross section be narrow and deep, the deposited matter will be restricted in area, and will accumulate in greater depth than is possible where, for instance, the cross section is wide, as in an expanded portion of the stream and the deposits are therefore distributed over a much larger area.

While it is literally true that no two streams are exactly alike, our average inland stream, of large creek or small river size, is, in Ohio topography, a succession of riffles and pools, these being numerous in the upper part of the stream, and becoming less frequent as, in the middle and lower reaches, the stream reduces its gradient and encounters wider valleys, with extensive flood plains. If the gradient as a whole is heavy, rather than slight, any considerable increase in the amount of water to be drained away, as in the event of a flood, obliterates the usual demarcations of riffle and pool, and to some degree flushes out the entire river channel with a continuously rapid current. The Scioto River is such a quick-spilling type of stream, and this fact must be considered in a study of the bottom sediments, for these are likely to be removed to some extent by such flushing.

As to the frequency of sampling, monthly samples seem to be satisfactory as a rule. This frequency is based mainly on two considerations: (1) the probability that monthly samples will furnish a sufficiently accurate representation of such physical and chemical changes as are bound to occur over a period of, say, 1 year or more, and (2) the similar probability that monthly samples will adequately reflect the major fluctuations of aquatic life as usually found in the bottom sediments. More specifically, item (1) above takes cognizance of the frequent periods of high water, with resultant flushing out of the less stable bottom sediments, and subsequent depositing of new material, silt, trash, etc., and the shifting of position, or perhaps the removal in toto, of such bottom organisms as are not anchored to flood-resistant objects such as rock, waterlogged trunks, or well-settled bottom mud. Eggs of chironomid insects, for example, are usually attached to stems, limbs, etc., and are not easily removed by an increased current—but egg-capsules of sludge worms, lying

singly and unattached on the surface of bottom sediment, without slime or other means of attachment, and having a specific gravity only slightly greater than 1.0, and further aided by their prevailing football shape—these capsules are obviously easily moved and transported by flood conditions, whereas the adult worms, with three-fourths of their body buried in the sediment, will be successfully dislodged only if the sediment itself be removed in considerable amounts.

Specific statement of item (2) above relates to the varying duration of life cycles of certain of the sediment population. Some organisms such as worms, bivalves, and fish are continuously present inasmuch as no state of the life cycle is other than aquatic. Other forms, notably the insects, beetles, and allied organisms periodically leave the aquatic environment, and take to the air as swarms of flies, bugs, etc. That is, the eggs, sometimes very minute, or the larvae, or the pupae of such organisms are to be found at one time or another, in the water environment. The mosquito is a well-known example. The midge larva is perhaps a better example, for it lives more consistently in the bottom sediment, our present problem. It is possible that the sediment sample taken monthly may occasionally contain many full-grown midge larvae, and the succeeding sample taken a month later at the same location may show very few or none at all, pupation and emergence having taken place in the meantime and the emerging imago having escaped to the air. Richardson (39) (1928) thus explains, in part, the heavy decrease in small bottom mollusks (*Sphaeriidae*) in the Illinois River by schools of bottom feeding fishes whereas this same upstream migration of food-seeking fish may have taken place at a time when the species of midge larva usually abundant was temporarily decreased by reason of recent pupation and emergence, and they thus escaped the depletion waged upon the luckless bivalves, which organisms have no period of emergence, but are permanent residents of the stream bottom.

The method of taking samples depends somewhat on the general character of the stream bottom. If this is soft, and rocks, submerged trash (such as limbs) are relatively absent from the selected sampling stations, conditions are favorable for taking a quantitative sample. The Ekman dredge is suitable for such, enclosing with its jaws a fixed area of the bottom, and sampling to the depth of about 6 inches. Richardson's valuable data relative to the amount of small bottom fauna (chiefly fish food) and expressed in pounds per acre, is based upon such samples as may be obtained with this dredge. But if the chosen sampling points present a variety of conditions such as sandy, stony, or trash-filled bottom, in addition to such sediments as may be present, the small dredge is unsuitable and a quantitative sample is all but impossible. About the only method possible is the use of a

strongly-made "mushroom" scoop, as shown in figure 15. The hoe-like action of this scoop will secure a qualitative sample of almost any sort of bottom found in the average stream. Because of its versatility, this scoop has been used on the variety of bottom presented by the Potomac, the Ohio, and the Illinois Rivers, and finally in the present study of the Scioto River.

Having experimented with collected samples of 200 ml., 500 ml. and 1 liter, it is believed that the bottom sediment sample should be at least one liter in amount. This is ample to ascertain the odor, the color, and the consistency or pastiness (degree of firmness or density). The smaller bottom fauna are usually present in this amount of sample, though sometimes very few, especially in the cleaner streams. Probably a 2-liter sample would be better in many instances. On the other hand, the sediments of a sewage-polluted stream are likely to contain very large numbers of sludge worms and moderate numbers of insect larvae, particularly those of midge. The required enumeration and identification of all these is a real task and this matter in turn becomes a factor in the amount of time available for this type of work in the study of a given stream.

Laboratory methods and examinations.—In making the laboratory examination of the sediment samples, ordinary quart Mason jars were found to be convenient containers. On collecting the sediment sample in the field, the jar was about 5/6 filled, 70 to 90 ml. of strong formalin were added, and mixed somewhat by tipping and inverting the jar. A label, written with ordinary soft lead pencil on a slip of strong paper, was placed inside, on top of the sediment.

On arrival at the laboratory the topmost level of the sediment was marked with grease pencil, on the outside of the jar. This gave the amount of sediment sample. Usually it was less than one liter, perhaps 600 or 800 ml.

For use in preparing the sample for examination, several 7 by 7 inch pieces of 30-mesh brass wire gauze were procured and made into strainers as shown in figure 37. In making the strainer the gauze was creased from the mid-point, *M*, of one side, to the center of the gauze *X*. This crease was partly straightened out and a crease made from *Z*, about 1 inch to the right of *M*, to *X*, but in the *reverse* direction, both creases meeting at *X*. The folding of *Z* over *M* then formed a shallow basin-like container through which the mud suspension was poured and strained.

In washing out the sample, both sides of the square of wire gauze previously prepared were wetted.

A portion of the sediment sample—one-fourth, more or less—was placed in a deep dish with strong handle (a 2-liter "miner's cup" proved excellent), tap water was added and agitated by shaking until some of the mud was in suspension, then this fine suspension was

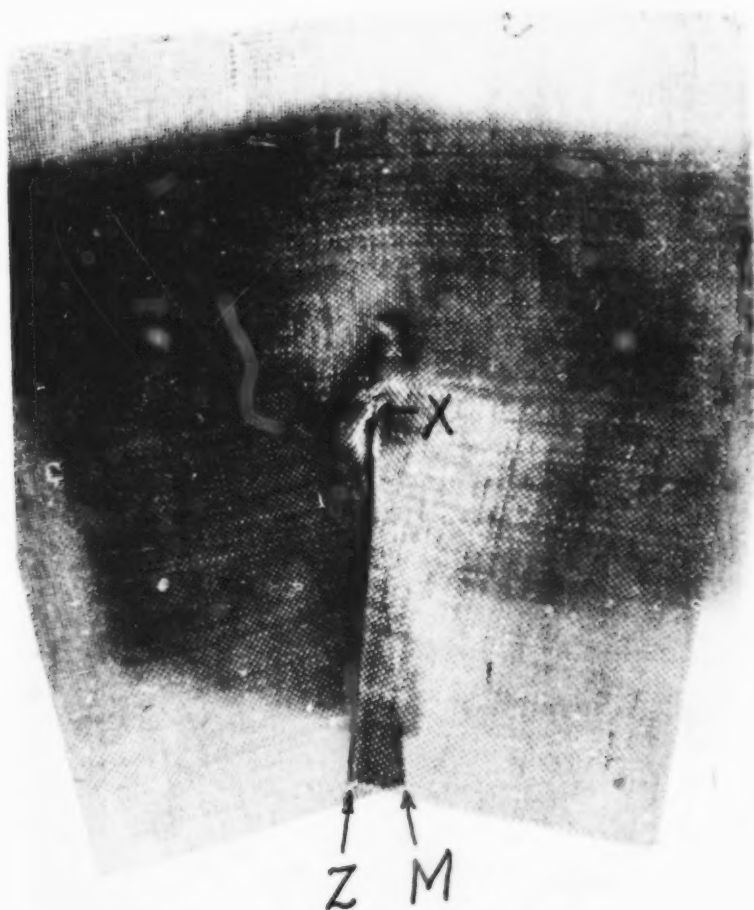


FIGURE 12. Strainer used in the washing of bottom sediment sample.

immediately poured through the gauze strainer, holding this over the sink. More water was added to the cup, the suspension poured through the strainer, and the process repeated. Masses of mud, not in suspension, should not be dropped on the gauze.

A large dish, such as a 10-inch moist chamber, was half filled with clean water and as the strainer accumulated leaves, trash, pebbles, worms, etc. it was turned upside down over this clean water and lowered until the water touched every part of the gauze. The "catch" on the gauze was thus transferred to the dish of clean water, and the gauze was then ready to continue the straining of additional portions of the suspension.

The above procedure was continued until all the sediment in the Mason jar sample had been washed through the gauze.

Leaves, trash, large pebbles, and the like were in some cases picked out of the "miner's cup" by hand—but these were examined for attached growths, such as algae, *Bryozoa* (pipe moss), masses of stalked ciliates, such as *Carchesium*, and the like. It also proved advisable to note the approximate proportions of such material as made up the sample. This may be 75 percent sand and pebbles, or it may be 25 percent plant detritus such as leaf fragments, bits of twig, chaff, etc.

With a little practice one should be able to detect a strong or moderate odor of sewage, even after formalin has been added to the sample. Some proficiency in the detection of such odors may be developed by obtaining a sample of sewage-polluted mud, unkilld, dividing it into two parts, adding formalin to one, but none to the other, and keeping these portions for a few days, comparing the respective odors meantime.

With the washing of the sample completed the catch was present in the large shallow dish. If the water was very turbid, all but a small amount was poured off. The larger leaves, trash, sticks, etc., were picked out and the contents of the dish were well distributed over the bottom. If the catch proved very heavy, a half, or a quarter of it, was transferred to another large shallow dish, counted, then multiplied by the proper factor.

An ordinary reading glass was useful in counting, as it enabled one to distinguish at once between the smaller tubificid worms, and the midge larvae. The larger Mayfly larvae, usually found in cleaner streams, were easily distinguished, unless they were very young. For identification of genera and species a low-power microscope proved indispensable.

The visible organisms of the bottom sediments do not vary a great deal in size—nothing comparable to the plankton for instance in which one of the larger organisms such as *Cyclops* might be equiva-

lent in volume to about 50,000 of the smaller organisms such as *Oocystis*. Beginning in 1923, the author (49) has, for this reason, consistently recorded his plankton values in terms of cubic standard units, in order that the various organisms might be *comparable*, and readily expressed as parts per million by volume. This is not so necessary in the case of the bottom sediment organisms, hence the author's departure from his usual practice in the present study. In the tables that follow, the organisms were merely counted.

If certain organisms are desired for further study or for future reference, they are easily preserved in about 5 percent formalin.

Apparent grouping of worms in the Scioto River.—The following table, XXXIII, shows the number of worms per liter of bottom

Table XXXIII.—Sludge worms per liter of bottom sediment at 3 stations in the polluted portion of the Scioto River

MONTHLY SAMPLES DURING 23 MONTHS

Month	Colum-bus	Shade-ville	Commer-cial Point	Month	Colum-bus	Shade-ville	Commer-cial Point
1937				1938—Continued			
August.....	10,000	36,000	3,500	September.....	8,000	6,700	6,100
September.....	6,200	6,700	(¹)	October.....	19,300	8,400	4,200
October.....	3,800	4,400	(¹)	November.....	520	15,000	2,800
November.....	300	31,900	10,500	December.....	5,100	15,300	11,800
December.....	2,800	460	5,500	1939			
1938				January.....	9,900	900	1,100
January.....	13,200	(¹)	(¹)	February.....	(¹)	(¹)	(¹)
February.....	(¹)	2,300	3,100	March.....	(¹)	(¹)	170
March.....	3,200	2,500	(¹)	April.....	7,400	1,200	8,900
April.....	5,300	14,100	5,900	May.....	85,600	26,900	34,100
May.....	1,900	1,100	1	June.....	40,100	6,000	5,500
June.....	130	270	44,200	Average.....			
July.....	250	4,700	25,000		11,270	9,722	10,693
August.....	2,400	9,600	20,500				

¹ No sample.

mud at three collecting stations in the polluted portion of the Scioto River. This is compiled from the several "Summary of Bottom Sediments" tables given elsewhere * * *, but using three stations only. Similar findings are in evidence at all stations but are less striking because of relatively small numbers of the worms. As sampling technique and the quantity of sediment examined were constant, there seems to be no adequate reason for the very sudden and very wide differences in the worm count shown in this table. Samples were taken at monthly intervals, except when occasional unusual flood conditions made this impossible, as in February and March 1939. Flood conditions capable of disturbing and removing bottom sediments would doubtless remove the younger worms in part, and the egg capsule also, these latter being unattached—but the larger worms burrowing at a depth of three to five inches, and capable of going deeper if disturbed—would certainly be much more difficult to remove.

Some suggestive inconsistencies are apparent in the above table. Lowering temperatures, apparently effective at Columbus in decreasing the counts of August, September, October, and November 1937, suddenly fail when in December the count goes up, and in January following the worm content is higher even than in August. A similar story is indicated by Shadeville samples, during about the same time period, but the sudden increase occurs in November instead of December. Advent of winter in 1938 shows similar inconsistencies in the worm counts at these two stations. Moreover, these stations, only 10 miles apart, show further differences when compared with each other: In July 1938, the count of 250 at Columbus and the nearly 20-fold increase at Shadeville might be explained by the sewage effluent discharge just above Shadeville, but in September and October, and in January 1939, the count goes the reverse direction, Columbus showing the higher count. Thus it is also in April, May, and June 1939.

Various other inconsistencies might be pointed out—the most incongruous being the counts in successive months of April, May, and June 1938, at Commercial Point, where a count of 5,900 was followed by a 1-liter sample in May containing only 1 worm, and the next month the same amount of bottom mud contained over 44,000 worms. Meantime the June counts at Columbus and Shadeville, a few miles upstream, were only 130 and 270, respectively.

I can offer no explanation for such hopelessly divergent values as are presented in these counts, except the one already suggested, namely, the habit of the worm to occur in scattered groups and colonies. The sampling dredge would most certainly contact varying members of these groups, and the mud sample thus secured would reflect, in the number of worms contained, the large element of chance involved.

Further confirmation as to worm groups is afforded by some laboratory cultures in use as this report is written. In a made-up medium consisting of sifted garden soil and fresh sewage solids, the components thoroughly mixed to secure uniformity, a population of 400 worms persists in arranging themselves in groups, in spite of the fact that the abundant organic matter available as food is uniformly mixed. Moreover, these groups change location every day or two, the groups further change in size and also in number. Occasionally all worms are in one group, but usually the arrangement is three or four groups. Only when available food becomes scarce do these groups break up as the worms go foraging.

Occasional difficulties of interpretation may be better understood, and partially cleared up, in view of this occurrence of tubificid worms *in groups* in a polluted stream. Thus Richardson's (39) comments on the tremendous differences in numbers of tubificid worms (see

page 13 of the reference cited) may be explained when we know that such variations are quite possible—in fact, are to be expected in view of the large element of chance introduced into the numbers of tubificid worms taken in a single sample.

In the present case of the various samples taken at Columbus, Shadeville and Commercial Point, the only means of getting order out of the inconsistent and chaotic individual counts is to consider the totals at each station, and to ascertain the average count. On doing this (table XXXIII) it is at once seen by these averages that the three stations named are on about the same sanitary basis so far as sludge worm population over a period of nearly two years can indicate the presence of pollution. If this be the true verdict, inspection of the above table item by item, that is, taking each month in turn, and noting the worm content as found at the three stations, will reveal the interesting fact that *no one set* of samples in the twenty sets recorded (August 1937 to June 1939 inclusive) can be interpreted as showing this same verdict. In one case only (see data of September 1938) is there any reasonable agreement as to number of worms in the three 1-liter samples. In other words, individual results, taken by themselves, are hopeless and impossible of interpretation. This again is evidence of the hit-or-miss results traceable in turn to the tendency of the worms to occur (1) in irregularly spaced groups, (2) of varying numbers each, and (3) of the consequent probability that the sampling apparatus may encounter several, few, or even none of these groups in taking a single sample.

In the absence of the foregoing facts relative to this grouping of the worms, the table presented would apparently be *prima facie* evidence to the effect that the sludge worm is, to say the least, a very poor indicator of organic pollution. Of the 16 complete sets (which are not lacking in one or more samples because of flood conditions) six sets indicate Columbus as exceeding in worm population, five sets similarly indicate Shadeville, and the remaining five sets indicate Commercial Point. This in itself would not be so much out of line but the two remaining counts of any given set usually lack any semblance of value approaching the one first stated, in spite of the geographical proximity of those three stations and their approximately equal chances of pollution. A pollutional organism content of 300, 31,900 and 10,100 (see November 1937) and of 2,800, 460, and 5,500 at the same stations the following month is not assuring to a logical thinker—and even more disastrous to confidence are the successive monthly values, in the above table for April, May, June, and July 1938. There must be some outstanding and constant factor of uncertainty to produce such erratic counts, in successive and nearby stations, as 1,900, 1,100, and 1 in May 1938 and 130, 270, and 44,200 at these same stations the following months. But all these discrepancies are not only possible,

that are probable, because of the lack of uniform distribution of the worms over the bottom sediment. I believe that, as an organism indicating the presence of organic pollution, the sludge worm is unsurpassed. It is quite possible that our methods of taking bottom samples are chiefly to blame, and that we must amend these methods in order to counteract the element of chance projected into the situation by the established habit of the worms to occur in irregular and temporary groups.

THE TABULATED DATA

In table XXXIV an effort is made to set forth outstanding biological conditions as found at a selected list of sampling stations—these stations, in turn representing sections of the river which are, according to available information (1) somewhat polluted by untreated sewage,

Table XXXIV.—Bottom sediments of the Scioto River and average content of organisms per liter of sample, (a) for each year, (b) for all collections

Station	Year	Number of samples	Pollutional (chiefly tubificid worms)		Tolerant (chiefly Chironomid larvae)		Cleaner (gill breathing insect larvae)	
			(a)	(b)	(a)	(b)	(a)	(b)
Columbus.....	1937	5	4,775		0		0	
	1938	11	5,391		0		0	
	1939	4	¹ 35,750	² 11,270	0		0	0
Shaderville.....	1937	5	15,892		4		0	
	1938	11	7,270		1+		0	
	1939	4	8,750	0,722	6	3	0	0
Commercial Point.....	1937	3	6,367		1		0	
	1938	10	12,300		5		0	
	1939	5	³ 9,954	³ 10,693	6	4	0	0
South Bloomfield.....	1937	5	418		13		2	
	1938	11	569		2		0	
	1939	6	667	634	1	4	0	¹ / ₂
Kellenberger Bridge.....	1937	5	147		5		0	¹ / ₂
	1938	11	109		8	6-	0	¹ / ₂
	1939	4	98	116	42		0	
Chillicothe.....	1937	5	27-		16		¹ / ₂	
	1938	10	42		18	23	2	¹ / ₂
	1939	4	119	54	253		7-	
Lucasville (and Waverly).....	1937	4	49-		6		1	
	1938	9	74		21	75	3	3
	1939	4	³ 34	³ 56				

¹ In one catch of 86,000, 79 percent were newly hatched.

² In one catch of 35,000, 47 percent were newly hatched.

³ In one collection of 127, 83 percent were newly hatched.

(2) heavily polluted by sewage effluent from the Columbus treatment plant, (3) recovered to different degrees, from the Columbus pollution. The accompanying list (table XXXV) further sets forth the details concerning these seven sampling points.

As indicated in table XXXIV, collection of bottom samples began in 1937, extended through 1938, and closed in 1939. Specifically, this began in August 1937, and continued until June, 1939. Samples were collected monthly. The three periods of varying sewage treatment at the Columbus sewage treatment plant were too short to afford an adequate and clearly visible reaction on the part of the

bottom organisms because of the longer life cycle of these organisms. That is, a few months would produce little or no visible change, whereas 2 or 3 years would be effective.

Table XXXV.—Collecting stations for bottom sediment samples, Scioto River

Station designation	River miles below Columbus	Zone	Pertinent data
Columbus	3	Above effluent outfall, but pollution of uncertain amount is caused by discharge of some untreated sewage.	At Greenlawn Avenue bridge just below overflow from the impounding dam at Columbus.
Shadeville	13	Polluted	5 miles above this point, the Columbus sewage plant effluent is discharged into the river.
Commercial Point	17	Polluted	The effluent-polluted water has flowed 12 miles. Time interval since pollution (29 hours at low water stage).
South Bloomfield	23	Polluted	The beginning of recovery is indicated. This is after a flow of 18 miles, and a time interval of 44 hours at low water.
Kellenburger Bridge	46	Recovery	Recovery continues. Miles of flow 41. Time—101 hours at low water.
Chillicothe	61	} Recovery	Recovery practically complete. Stream is relatively clean. 275 hours at low water.
Lucasville	115		

Table XXXIV is constructed on the assumption (to be discussed later) that we have sufficient warrant to classify tubificid worms as "pollutional" organisms (that is, when numerous, they are indicative of an environment containing much putrescible organic matter), and further, that chironomid larvae, as a group, are capable of enduring a considerable degree of pollution (that is, they are "tolerant"), and finally, that such insect larvae as are found chiefly in relatively clean waters containing a normal population of fish—these organisms are briefly and justly classified as "cleaner."

Brief consideration of the several stations in table XXXIV is now in order. At the Columbus sampling station, 5 collections in 1937 averaged 4,775 worms each; 11 collections in 1938 averaged 5,391 each, and 4 taken in 1939 averaged 35,750 each. (See section marked "pollutional," and column (a)). The totals of these 20 collections (stated in table XXXIII, see p. 118) give an average, for all collections, of 11,270 worms per collection (see column (b) in table XXXIV).

It is to be noted meantime, that at this same station, the bottom sediments furnished no "tolerant" organisms. The "cleaner" organisms were likewise entirely absent.

Similar inspection of the data given by Shadeville and Commercial Point shows that these stations yield averages of 9,722 and 10,693 worms, respectively (see column (b)), and that "tolerant" organisms are present in very small numbers—averages of 3 and 4, respectively. Meantime the "cleaner" organisms are entirely absent.

Continuing this inspection of the remaining data given in table XXXIV we note, in brief:

(1) Beginning with South Bloomfield, the average number of pollutional organisms (column (b) in section "Pollutional") decreases rapidly, and with reasonable uniformity, ending with an average content, at Chillicothe and Lucasville, of 58.

(2) Tolerant organisms meantime increase slowly from an average of 3 and 4 in the polluted portion of the river to an average of 75 in the fully-recovered river at the lowermost station, Lucasville.

(3) Cleaner organisms, entirely absent from the uppermost three stations, increase very slowly, finally showing an average of 3 at the lowermost station.

The outstanding item of table XXXIV is the heavy decrease of sludge worms from about 10,000 per liter in the polluted upper river to about one-half of 1 percent of that number in the recovered relatively clean stream in the Chillicothe-Lucasville section. This net result is based on all of the bottom samples taken, 138 in all.

A second item of significance is that the three uppermost stations show approximately equal average numbers (see column (b)) of pollutional organisms, and apparently are on about the same sanitary basis, in spite of the fact that the Columbus station is 2 miles upstream from the sewage effluent outfall. On careful inquiry it is found that, due largely to difficulties of gradient, a few of Columbus' sewers discharged their untreated contents directly into the river at and near the city. There was also some discharge of storm water overflow from combined sewers. This apparently provides bottom deposits from the limited volume of water below the impounding dam which are about equal to those caused, a few miles downstream, by the much larger contribution of effluent from the sewage treatment plant. This effluent is undoubtedly much less harmful to the stream than the raw sewage, volume for volume, but apparently bottom deposits from the smaller volume of the highly potent raw sewage plus storm water overflows are about evenly pitted against those from the larger volume of the weaker effluent.

PRESENTATION OF DATA, STATION BY STATION

The tabulated data are stated in more detail in tables XXXVI to XLII for each station that follows herewith. These tables of laboratory findings, together with observations made in the field at the several stations considered, constitute the chief basic data which warrant the brief discussion of the prevailing situation and which, summarized, support the tentative conclusions relative to the sanitary status of the Scioto River as indicated by a study of the bottom sediments.

Table XXXVI.—Summary of Scioto River bottom sediments at Columbus

Month	Physical condition	Organisms in 1 liter		
		Pollutational (worms)	Tolerant (chirono- mid larvae, etc.)	Cleaner (gill- breathers)
1937				
August	Black, gaseous, tarry odor, street washings present.	(1) (6) 10,000		
September	Black, bad odor, much plant detritus present.	(1) (6) 6,200		
October	Black, sandy, tarry odor. Plant detritus and street washings=50 percent.	(1) 3,900 (2) 320		
November	Black, sand and cinders=5 percent. Odor of sewage. Plant detritus.	(1) 300 (2) 21		
December	Black, tarry and fecal odor. Sand and cinders=10 percent.	(1) (7) 2,780		
1938				
January	Black, no special odor	(1) 12,040 (2) (7) 205		
March	Black, gaseous, strong sewage odor	(1) 3,240		
April	Black, strong odor of sewage	(1) 5,280 (2) 18		
May	Black, sand and cinders=20 percent. Odor of sewage.	(1) 1,790 (2) 92		
June	Black, no special odor. Cinders and sand=8 percent. Much plant detritus and street washings.	(1) 120 (2) (6) 13		
July	Black, sandy, has sewage odor	(1) 250 (2) (9) 4		
August	Black, has sewage odor. Plant detritus and cinders present.	(1) 2,370 (2) (10) 37		
September	Black, granular (8 percent sand). Odor of sewage.	(1) 7,640 (2) (9) 347		
October	Black, livery, has odor of sewage.	(1) 17,930 (2) (9) 1,400		
November	Black, livery, sewage odor. Detritus of plants, chaff and cinders.	(1) 309 (2) 18		
December	Black, livery, sewage odor. Plant detritus present.	(1) 4,830 (2) 305		
1939				
January	Black, livery. Strong sewage odor	(1) 5,800 (2) 159		
April	Dark color. Sand, cinders and pebbles=43 percent. Strong odor of sewage decomposition.	(1) 7,450		
May	Nearly black. A little sand present. Strong sewage odor.	(1) (11) 75,240 (2) 10,390 (4) (12) 865		
June	Nearly black. About 30 percent sand and pebbles. Sewage odor.	(1) (13) 37,000 (2) 3,120 (4) 1,140 (3) (14) 4,830		

(1) *Limnodrilus*. (2) *Tubifex*. (3) *Multicetus*. (4) Naid worms chiefly *Dero*. (5) *Aulophorus*. (6) Majority were malformed. (7) Majority knotted and malformed. (8) Worms normal. (9) A few worms abnormal. (10) 12 percent abnormal. (11) $\frac{3}{4}$ newly hatched. (12) Worms comprise 21 percent of mud sample by volume. (13) $\frac{1}{4}$ newly hatched. (14) Worms comprised 22 percent of mud sample by volume (after 30 minutes settling in graduate).

No samples collected February 1938, February and March 1939.

Columbus (Table XXXVI).—The channel at Columbus is about 200 feet from bank—but only a small part is occupied by flowing water, this being due chiefly to the fact that an impounding dam 4 miles above the sampling point (Greenlawn Avenue Bridge) collects the greater part of the stream flow. This dam provides the water supply for the city. The greater part of the Scioto River flow during low water is thus collected in this dam, by-passed through the water-mains and the service pipes, and later through sewers of the city to the sewage treatment plant, thence the sewage effluent is

discharged about 2 miles below the city and re-enters the channel of the Scioto River about 8 miles above the Shadeville Bridge.

Apparently some sewage and street washings find their way directly into this reduced stream flow above Greenlawn Avenue Bridge. This is indicated by the persistent physical conditions noted in the bottom sediments; practically every sample is black, or nearly so. This color alone is not necessarily indicative of sewage pollution, but when, in addition, there is a definite sewage or fecal odor in 18 of the 20 samples collected, the evidence of pollution is not to be ignored. Street washings are indicated in several samples by the presence of bottle caps, bits of tinfoil, shreds of paper, and chaffy material.

The organism content, necessarily limited to such forms as are able to endure the physical conditions already mentioned, consists entirely of tubificid worms. There are no insect larvae, even of the tolerant chironomids, in any of the 20 samples examined. This is clear-cut and definite response of such organisms as are known to prefer sewage pollution; they are present in large numbers. Just as clear-cut, also, is the response of such organisms as cannot endure extreme sewage pollution; they are entirely absent.

Further evidence of the general suitability of the environment for these pollutional tubificid worms is noted in the occasional presence of large numbers of young worms, as in the samples of May and June 1939.

There is, however, some unknown condition unfavorable to the worms. In at least 8 of the 20 samples, many worms were abnormal in that they were knotted and malformed. The normal smooth, uniformly cylindrical body had become a series of humps and contractions usually alternating, and presenting a roughly beaded appearance. Moreover, this beaded portion, always beginning at the anal end and progressing toward the anterior end, seemed to be in reality a process of death. Observations on living worms in laboratory cultures indicated that the alimentary canal in this portion is usually empty, the blood circulation slow, and the amount of blood abnormally small, the worm body in consequence being somewhat colorless or whitish. This apparently dying abnormal portion of the body sloughed off a part of its length from time to time. There seemed to be no taking of food meantime by the still active and normal anterior end of the living worm. It is possible that this is the manner of its normal death—that it “dies by inches” so to speak, and that the dead and putrescible organic matter of its body is consigned to the environment a little at a time, thus avoiding, in an environment usually very low in dissolved oxygen, the sudden and considerable burden that might be imposed if the entire body of the worm in considerable numbers became lifeless and therefore putrescible.

This condition of tubificid worms was observed in the Columbus samples much more frequently than at any other station. At most of the other stations it was noted only once, but at Chillicothe the condition appeared in 3 of the 19 samples. It is possible that some industrial waste may encourage this sloughing-off process in the Columbus samples. The trouble at this station surely is not due to lack of food. At Chillicothe, however, the environment is relatively clean, organic matter is scarce, no odor being noticeable, and worms are present only in very small numbers, the most reasonable cause for this latter being the evident lack of food. It is possible that this same lack is the chief reason for the sloughing-off process—the gradual death—noted in three of the Chillicothe samples.

Table XXXVII.—Summary of Scioto River bottom sediments at Shadeville

Table XXXVII.—Summary of Scud Data

Month	Physical condition	Organisms in 1 liter		
		Pollutional (worms)	Tolerant (chironomid larvae, etc.)	Cleaner (gill-breathing larvae)
1937				
August	Chiefly pebbles. Very little mud. Strong sewage odor. Detritus (and worms) on pebbles. Some algae also on pebbles.	(1)26,000		
September	Black. Strong sewage odor. About 75 percent sample was sand and pebbles.	(1)6,700		
October	Black. Strong sewage odor. Sample was 80 percent gravel and sand.	(1)4,400		
November	Black. Has sewage odor. Small amount of sand in sample.	(1)31,900	(5)24	
December	Black. Has tarry odor. Sand and plant detritus present.	(4)2,700 (1)465		
1938				
February	Black. Moderate odor only. Very little detritus.	(1)2,300 (6)		
March	Black, sticky. Has sewage odor. Sand forms 5 percent of sample.	(1)2,460 (7)		
April	Black, sticky. Has sewage odor and 1 percent sand.	(1)14,100 (8)		
May	Black and sticky. Sewage odor. Has 2 percent sand.	(1)1,050 (2)21 (9)		
June	Black, rather firm. "Privy odor." Cinders, sand, etc. form 18 percent of sample.	(1)220 (2)50		
July	Black, mod. firm. Has odor of sewage. Sand forms 36 percent of sample.	(1)4,700 (2)24, (8)		
August	Black, sandy, has odor of sewage. Small amount detritus present.	(1)9,325 (2)265	(10)8	
September	Black, livery. Has sewage odor.	(1)6,720		
October	Black, livery. Has odor of sewage. Very little detritus.	(1)8,375		
November	Black, soft. Strong odor of sewage.	(1)15,000	(10)5	
December	Black, soft. Moderate sewage odor. 20 percent of sample is leaf fragments and plant detritus.	(1)14,300 (2)1,000 (4)1,700		
1939				
January	Black, soft. Strong sewage odor.	(1)900 (3)20, (8)		
April	Black, soft, gaseous. Strong odor of sewage. Contains a little sand.	(1)1,200 (2)25		
May	Black, granular. Sewage odor. Total volume worms (about one-third recently hatched) 16 percent of mud sample.	(1)21,800 (2)5,100		
June	Black, soft, livery. Strong sewage odor.	(1)5,725 (2)325	(10)25	

(1) *Limnodrilus*, (2) *Tubifex*, (3) *Multistotus*, (4) *Dero*, (5) *Sphaeriidae*, (6) Majority knotted and abnormal (7) Egg capsules present, (8) Many egg capsules, (9) Few egg capsules, (10) Chironomid larvae.
No samples collected in January 1938 and February and March 1939.

Shadeville (Table XXXVII).—In the Shadeville region the valley is wide, and consists chiefly of farm lands. The river channel has a border of trees, mostly deciduous, on either side occupying the frequently flooded lowlands constituting the river banks.

About 8 miles above this point, the effluent of the Columbus sewage treatment plant enters the stream. A quarter mile or less below the outfall a few riffles operate to produce more perfect mixture of this effluent with the river water.

To an observer standing on the bridge at Shadeville the most noticeable item of this situation is the persistent and moderately strong odor of sewage. On inspection of the shallow stream, there is seen, especially near the margins, numerous patches and groups of reddish, tubificid worms.

The 20 monthly samples of bottom sediment obtained at this station are in agreement as to color and odor. All are black, and all have a strong sewage odor, sometimes a "foul privy odor." Half or more of the samples show a good proportion of sand or small pebbles, or both. Leaf fragments, scraps of bark, bits of twigs, most of them black and partly decomposed, are found in a third of the samples.

Tubifex worms dominated the situation, as they did at Columbus, occurring in every sample in numbers varying from a few hundred to thirty-six thousand per liter of bottom samples. Other organisms were present only infrequently and in relatively small numbers—*Chironomid* larvae in four samples and the sewage-tolerant bivalve *Sphaeriidae* in one sample. It was evident that the worms were in suitable environment, being present in every sample. Moreover, their egg-capsules were frequently present and sometimes numerous.

With regard to sewage odor, distinction should be made between the prevalent air odor, perceptible as the observer stands near the stream—and the odor of the bottom sediments, when these are removed from the stream and are exposed to the air. It is frequently the case that such sediments when removed and tested, have a definite sewage odor, but this same portion of stream as a whole, yields no odor to the passer-by or to the average visitor. Thus little or no air odor is observable at Columbus, or at Commercial Point, or at South Bloomfield, but the bottom sediments at these places when removed from the stream have a very definite sewage odor. At Shadeville this odor of the removed sediments is especially bad—a vile "privy odor." Enough of this odor is imparted to the air (as the water flows, with frequent overturns and exposures to the air) to give the *atmosphere* a sewage odor perceptible to the visitor who crosses the bridge at this place.

Table XXXVIII.—Summary of Scioto River bottom sediments at Commercial Point

Month	Physical conditions	Organisms in 1 liter		
		Pollutional (worms)	Tolerant (chironomid larvae, etc.)	Cleaner (gill-breathing larvae)
1937				
August	Grayish mud, containing sand and pebbles. Moderate odor of sewage.	(1) 3, 500	(6) 3	
November	Black and sandy. Has odor of sewage. Plant detritus present.	(1) 8, 820 (2) 1, 300 (3) 420	(7) 2	
December	Black. Contains sand. Has odor of sewage. Detritus present.	(1) 8, 490		
1938				
February	Black, sticky. A small amount of sand. Sewage odor present.	(1) 3, 100		
April	Black, soft. Detritus (plant) 20 percent and sand 10 percent sample. Sewage odor present.	(1) 5, 100 (2) 840 (3) 120		
May	Black, gaseous. Has odor of sewage. Some plant detritus present.	(1) 1 (8)		
June	Black, soft. Has marked sewage odor. Some plant detritus present.	(1) 38, 000 (2) 6, 160 (3) 280		
July	Black, livery, soft. Odor of sewage present.	(1) 25, 000		
August	Black, soft. Has odor of sewage.	(1) 20, 000 (2) 510 (3) 530	(6) 15	
September	Dark, nearly black, and soft. Has odor of sewage.	(1) 5, 820 (2) 320 (3) 320		
October	Black, soft and stinking (odor of sewage). Plant detritus present.	(1) 4, 100 (2) 100 (3) 675	(6) 25	
November	Black, soft. Sewage odor. Leaf fragments and plant detritus present.	(1) 2, 800	(6) 6	
December	Black, soft. Has odor of sewage. Leaf fragments present.	(1) 11, 000 (2) 750 (3) 500		
1939				
January	Black and soft. Has odor of sewage. Plant detritus present.	(1) 1, 000 (2) 100, (3) 20		
March	Black, rather stiff and firm. About 2 percent sand. No sewage odor. Strong formalin odor. Much plant detritus present, also pupa cases of Psychoda.	(1) 170 (8)		
April	Black, sticky. Has odor of decomposition. Leaf fragments, etc., present.	(1) 8, 000 (2) 900, (10)		
May	Grayish black, soft. Has odor of sewage. About 50 percent worms newly hatched.	(1) 23, 800 (2) 11, 300	(7) 2	
June	Nearly black, soft. Has a strong sewage odor.	(1) 5, 200 (2) 250	(11) 30	

(1) *Limnodrilus*, (2) *Tubifex*, (3) *Multisetosus*, (4) *Dero*, (5) *Aulophorus*, (6) Chironomid larvae, (7) Leech, (8) See text page 120, (9) Many worms abnormal, (10) Many egg capsules, (11) *Sphaeridia*.
No samples taken in September, October, 1937; January, March, 1938 and February, 1939.

Commercial Point (table XXXVIII).—General topography and channel conditions are quite similar to those of Shadeville—low wooded banks, a stream about 200 feet wide, flowing rather slowly. In one particular, however, this station differs. The odor of sewage is faint, even lacking at times. Occasionally it may be quite apparent to a sensitive visitor. Consistent with this change, the tubificid worms are not so apparent. A few spots or groups can be seen, but fewer of these are visible, at least in the marginal waters, than at Shadeville.

Most of the bottom samples are black, but a few are grayish. In this, as in the decreased intensity of odor, there is a little difference, as compared with the Shadeville samples.

Every sample contained tubificid worms. The maximum number was 44,000, the minimum 1 (a single worm!) per liter of sediment. Average of the 18 samples, 10,693 (see table XXXIV).

Chironomid larvae were present in rather small numbers, in 4 samples, and the tolerant bivalve, *Sphaeriidae*, in 1 sample. Thus, biologically, as well as physically, conditions are quite similar to those of Shadeville.

Table XXXIX.—Summary of Scioto River bottom sediments at South Bloomfield

Month	Physical condition	Organisms in 1 liter		
		Pollutional (worms)	Tolerant (chironomid larvae, etc.)	Cleaner (gill-breathers)
1937				
August.....	Dark color. Odor slight. Sample chiefly sand and gravel. Some detritus.	(1)1,050	(6)2	-----
September.....	Dark. About 80 percent sand and gravel. No special odor.	(1)342	(7)2	-----
October.....	Dark. 50 percent sand and gravel. Strong odor of sewage. Plant detritus present.	(1)230 (2)88 (3)10	(8)11	(9)1
November.....	Black. Has strong sewage odor. Small amount sand and gravel.	(1)178, (2)24 (3)88, (4)16	(10)8	-----
December.....	Black, slimy. Tarry odor. Contains chaffy material, like bits of hay.	(1)56 (2)5, (4)5	(7)32	-----
1938				
January.....	Dark. Contains small amounts of sand, also 5 percent leaf fragments.	(1)156 (2)6, (3)6	(6)6 (7)24	-----
February.....	Black, slimy. Has moderate sewage odor. Much minute plant detritus.	(1)64	(11)5	-----
March.....	Black, sticky, gaseous. Strong sewage odor. Contains plant detritus, from field or streets.	(1)96 (2)8	-----	-----
May.....	Dark, granular, with 12 percent sand. Sewage odor. Plant detritus.	(1)280 (2)20	-----	-----
June.....	Black, soft, livery. Has sewage odor. 7 percent sand.	(1)770 (2)34, (3)5	-----	-----
July.....	Nearly black, soft. Sewage odor. A little sand. Plant detritus.	(1)2, 100 (3) (12)25	-----	-----
August.....	Black, sticky. Moderate sewage odor. Sand 4 percent.	(1)1, 160 (2)50	-----	-----
September.....	Black, livery, not granular. Slight sewage odor.	(1)500	-----	-----
October.....	Black, livery. Has some odor of sewage. Plant detritus.	(2)12, (3)12 (1)60 (2)3	-----	-----
November.....	Black, soft. Has sewage odor. Plant detritus, and <i>Psychoda</i> molts.	(1)500 (2)40	-----	-----
December.....	Black, soft. Has strong odor of sewage.....	(1)265, (2)13 (3)27, (4)13	-----	-----
1939				
January.....	Black and gray, soft. Has sewage odor and much fine detritus.	(1)100 (3)2(4)3	-----	-----
March.....	Dark grayish. Sewage odor. Fine detritus present.	(1)600 (2)110	-----	-----
April.....	Grayish, soft, granular. 1/6 of sample is sand. Sewage odor.	(1)500	-----	-----
May.....	Dark, soft, pasty. Odor of sewage. Plant detritus present.	(1)1, 540 (2)6(3)117	(7)6	(13)2
June.....	Nearly black, sticky. Has sewage odor.....	(1)1, 728 (2)456 (4)112	-----	-----

(1) *Limnodrilus*, (2) *Tubifex*, (3) *Multicetus*, (4) *Dero*, (5) *Aulophorus*, (6) Leech, (7) Chironomid larvae, (8) *Corsethira* larvae, (9) Caddis larvae, (10) *Aesellus aquaticus*, (11) *Psychoda* larvae, (12) A few egg capsules present. (13) May-fly nymphs.

No samples April, 1938 and February, 1939.

South Bloomfield (table XXXIX).—This station, 6 miles below Commercial Point, shows no essential departure, as to topography, from the up-stream station mentioned. The stream is about 200 feet wide. No worm-groups are visible, and there is no atmospheric odor of sewage. Submerged water plants (apparently a potamogeton) are moderately abundant. Below the bridge a riffle shows a heavy growth of a submerged, grass-like plant (not an alga).

About half of the 21 samples taken show varying amounts of sand and gravel, twenty have a sewage odor, this being strong in five samples. Color of bottom samples is usually black, or at least dark, but an occasional sample is gray. Leaf fragments and decomposing plant detritus are noted in thirteen samples.

Tubificid worms appear in every sample, but only five yield over 1000 per liter, and the maximum is not quite 2200. Remaining samples vary from 60 to 800 worms per liter of sediment, and these low values are the chief factor in forcing the station average (see table XXXIV) down to 634.

Chironomid larvae appear in four samples, and a lessening of prevailing pollutional conditions is foreshadowed by the appearance of other organisms in three samples—*Corethra* larvae and one caddis-fly larva in one sample, and the crustacean *Asellus aquaticus* in another, and May-fly nymphs in a third. None of these are found, as a rule, under conditions of heavy pollution. The caddis- and May-fly larvae in particular possess external gills, and require oxygen-containing water for the proper functioning of those gills.

Table XL.—Summary of Scioto River bottom sediments at Kellenberger Bridge

Month	Physical condition	Organisms in 1 liter		
		Pollutional (worms)	Tolerant (chiron- omid larvae, etc.)	Cleaner (gill- breathing larvae)
1937				
August.....	Brownish, with a little sand. No odor. (Long pool at this station.)	(1)20	(6)4	.....
September.....	Brownish, with a little sand. No odor. Some detritus.	(1)128	(6)4	.....
October.....	Brownish, soft. About 10 percent sand. No special odor.	(1)412 (2)24	(6)1	.....
November.....	Brownish, sticky. Small amount sand and detritus. Slight sewage odor.	(1)66 (2)12	(6)3	.....
December.....	Brownish, granular. Contains a little sand. No odor.	(4)30 (1)43 (7)	(6)16	.....
1938				
February.....	Brownish. Traces of sand and detritus. No odor of sewage.	(1)32	(6)8	.....
March.....	Brownish. No special odor.	(1)18	(6)2	.....
April.....	Grayish, sticky. Leaf fragments and a little sand present.	(1)16	(6)3	.....

See footnote at end of table.

Table XL.—Summary of Scioto River bottom sediments at Kellenberger Bridge—Continued

Month	Physical condition	Organisms in 1 liter		
		Pollutional (worms)	Tolerant (chironomid larvae, etc.)	Cleaner (gill-breathing larvae)
1938				
May	Brownish. No special odor. Leaves and sticks comprise 5 percent of sample.	(1)27		
June	Grayish. No odor. Moderate amount of plant detritus.	(1)116 (2)2	(6)2	(8)4
July	65 percent sand and pebbles. Mud grayish, with slight odor. Plant detritus present.	(1)146 (2)4 (4)140 (1)120	(6)9	
August	Grayish, soft. No odor. 9 percent of sample was sand.	(1)55	(6)2	
September	Grayish. More than 40 percent sand. No odor of sewage. Plant detritus present.	(2)7 (1)155	(6)15	
October	1/4 sand and pebbles. Mud brownish. No odor.	(2)15 (1)80	(6)4	
November	Nearly 1/4 sand and pebbles. Mud brownish. Slight odor of sewage.	(2)23 (1)220	(6)6	
December	Dark colored. Has sewage odor. 72 percent sand and gravel. Fragments of stem, leaves, bark, etc., present.	(4)21		
1939				
January	Gray-brown. Has slight odor of sewage.	(1)36 (3)2 (4)8	(6)9	
April	Grayish. Granular. Has slight odor of sewage. Contains sticks and leaves.	(1)40 (2)2 (4)12	(9)4	
May	9/10 sand and pebbles. Moderate odor of sewage.	(1)26 (2)2	(6)19	
June	Nearly black. Firm rather than soft. Much plant detritus. Moderate odor of sewage.	(1)250 (2)12	(10)2	

(1) *Lumbriculus*, (2) *Tubifex*, (3) *Multisetosus*, (4) *Dero*, (5) *Aulophorus*, (6) Chironomid larvae, (7) Several species of normal, (8) May-fly nymphs (*Ephemera*), (9) *Ceratopogon* larvae, (10) May-fly nymphs (*Hesperia*).
 No samples collected in January 1938, and February and March, 1939.

Kellenberger Bridge (table XL).—This station represents an additional flow of 23 miles. The stream, about 200 feet wide, is apparently a shallow pool, perhaps 500 yards long, at this point. There is no odor as the observer stands near the stream, and no external indication of sewage pollution.

Twenty sediment samples were taken. In 11 the color was brownish, in the others gray, with a single sample (June 1939) almost black. In one sample, color was not recorded. As to odor, 11 showed no odor, 7 showed slight odor of sewage, 1 showed definite sewage odor. As to make-up, all but 3 showed a relatively high proportion of sediment, with very little sand or pebbles. In one case only (May 1939) did the sample show more than 50 percent sand and pebbles. Also, there were relatively small or moderate amounts of leaf fragments, bits of twig, and other plant detritus in the majority of the samples.

The great predominance of tubificid worms noted in the preceding up-stream stations here shows a definite change. In only one sample

(that of October 1937) do the sludge worms exceed 300 per liter of mud. In 9 samples the worm content is less than 300 but more than 100. In 7 samples the number of worms present is over 25 but less than 100, and in 3 samples fewer than 25 worms are present. Every sample shows some worms present, but in such diminished numbers that the average for this station is 116—about 1 percent of the average content shown in samples from the 3 stations in the upper polluted section of the river.

Further evidence of definite improvement in the stream bottom is shown by the increasing frequency of such organisms as are known to be tolerant of sewage pollution (so long as this is not excessive). Reference is made to the *Chironomid* larvae. These occur in 16 of the 20 samples. This is about 8 times as frequent as the occurrence of *Chironomid* at the 3 stations in the upper polluted river (Columbus, Shadeville, and Commercial Point). Moreover, in three Kellenberger samples are found a few organisms, chiefly May-fly larvae, which are important in the natural food supply of fish, and such larvae are to be found, as a rule, in waters that are clean enough to sustain fish life.

Summarizing, we may say that sediment samples at Kellenberger Bridge:—

1. Show much less odor than at up-stream stations.
2. Prevailing color is brownish.
3. Tubificid worms are greatly reduced in number.
4. Pollution-tolerant organisms occur in greater frequency.
5. Insect larvae (chiefly *Hexagenia*) characteristic of the cleaner, fish-inhabited waters, are occasionally present.

Table XII.—Summary of Scioto River bottom sediments at Chillicothe

Month	Physical condition	Organisms in 1 liter		
		Pollutional (worms)	Tolerant (chironomid larvae, etc.)	Cleaner (gill breathers)
1937				
August	Practically all pebbles and sand. No odor.	No organisms found		
September	95 percent sand and gravel. No odor.	(1)4	(5)18	
October	Over 90 percent sand and gravel. No odor.	(1)1	(5)112	
November	Yellowish mud. Sample 50 percent sand. No odor. Plant detritus.	(1)84	(5)48	
December	Brownish, about ¼ sand. No odor. Small amount of detritus.	(1)32	(5)30	
1938				
February	Dark. No special odor. About 3-percent leaves and sand.	(1)11	(5)732	
March	Chiefly fine sand. No odor.	(2)1		
April	Brownish. No odor. Cinders and plant detritus present.	(1)28	(5)6	
May	Yellowish. No odor. About 30-percent sand and gravel.	(1)27	(5)18	
July	Gray-brown, granular. Half sand. No odor. Plant detritus present.	(2)7		
		(1)6		

See footnote at end of table.

Table XLI.—Summary of Scioto River bottom sediments at Chillicothe—Continued

Month	Physical condition	Organisms in 1 liter		
		Pollutional (worms)	Tolerant (chironomid larvae, etc.)	Cleaner (gill-breathers)
1938				
August	Grayish. 60-percent sand and pebbles. Plant detritus present.	(1)18		
September	Gray-brown, granular. No odor. $\frac{3}{4}$ of sample sand.	(1)27 (9)		
October	Yellowish. 70 percent sand and pebbles. Leaf fragments and plant detritus. Slight odor of sewage.	(1)20 (9)	(5)10	
November	Brownish. 50-percent sand and gravel. No definite odor of sewage.	(1)148 (4)16	(5)1036 (5)16	
December	Brownish, dark. Has faint odor of sewage. Much plant detritus.	(1)148 (4)16	(5)1036 (5)16	
1939				
January	Grayish, granular. 5-percent sand and gravel. Very slight odor. Plant detritus present.	(1) (11)12 (2)14 (4)70	(10)14 (5)13 (6)58	(8)1 (12)1
April	Grayish, granular. Has slight odor of sewage.	(1)40 (2)2	(5)4	(8)5
May	Nearly all sand. Slight odor of sewage.	(1) (13)65 (2)17 (4)187	(5)35 (14)2 (15)2	
June	Chiefly coarse sand. Slight odor of sewage.	(1)8 (2)2		

(1) *Limnodrilus*, (2) *Tubifex*, (3) *Multisetorus*, (4) *Dero* and other Naididae, (5) Chironomid larvae, (6) Sphaeriidae, (7) Chiefly *C. plumosus*, (8) *Iteagenia*, (9) Several abnormal and knotted, (10) Chiefly *C. decorus*, (11) Majority newly hatched, (12) *Isoperla*, (13) Many abnormal, (14) *Psychoda* larvae, (15) *Ceratopogon*.

No samples collected in January and June 1938, or February and March 1939.

Chillicothe (table XLI).—This station is about midway of the 115 mile section of river included in this study. The stream here is about 150 feet wide. There is no odor. To the naked eye this clean-looking stream offers no suggestion of pollution.

The river bottom consists largely of sand and gravel. Material sedimented from the passing water is smaller in amount than that at up-stream stations discussed in the preceding pages. This paucity of sedimented material may be due in part to the narrower stream channel with consequent increase in current velocity, this in turn resulting in greater carrying power affecting the suspended matter and preventing its settling.

Recorded data show that 19 bottom samples were collected. Of this number, 12 contained from 50 percent to 100 percent sand and small gravel. Of the remainder, 4 contained less than 50 percent. Twelve samples showed no odor. The remaining samples had a perceptible odor of sewage. Prevailing color of these bottom samples was brown, or yellowish.

Eighteen samples (all but one) contained tubificid worms. In only two samples did the worms exceed 100. In nine samples worms numbered 25 to 100. Tubificid average for the station was 54.

Tolerant organisms, chiefly *Chironomid* larvae, appeared in 13 samples, and cleaner-water forms, chiefly the May-fly larva *Hexagenia* were found in 3 samples and the stone-fly larva *Isoperla*, commonly found in relatively clean streams, was present in one sample.

In brief, bottom sediments from this half-way station, Chillicothe, show much the same situation as do sediments from the station at Kellenberger Bridge, 15 miles up-stream for:

1. Sewage odor is lacking—or is faintly perceptible in a few samples only.
2. Tubificid worms are present in small numbers only, the station average being 54.
3. Pollution-tolerant organisms appear in a majority of the samples and cleaner-water organisms in small numbers in a few samples.

Lucasville (table XLII).—This station is 112 miles down-stream from Columbus, and is therefore 110 miles below the point where the Scioto River is polluted by the discharge of effluent from the Columbus sewage treatment plant. It is also 54 miles below Chillicothe, at which place a population of about 20,000 (70 percent served with sewerage) is responsible for a relatively small secondary pollution by the discharge, into the river, of about one million gallons per day of settled sewage. In addition, Paint Creek, a tributary below Chillicothe, adds some industrial waste from paper mills, and also a moderate but intermittent contribution of stockyard waste. The total of all these contributions would seem to be relatively insignificant in amount as compared with the pollution, in the upper river, by the effluent from the Columbus sewage treatment plant.

Table XLII.—Summary of Scioto River bottom sediments at Lucasville

Month	Physical condition	Organisms in 1 liter		
		Pollutional (worms)	Tolerant (chirono- mid larvae, etc.)	Cleaner (gill- breathing larvae)
1937				
August.....	Yellowish mud-and-sand, half and half. No odor.	(1) 60 (6) 80	(7) 300	.....
September.....	About 90 percent sand and gravel with a little mud. No odor.	(1) 10	(7) 44	(8) 2
October.....	96 percent sand and gravel. No odor.	(1) 0	(7) 772	(9) 12
November.....	Brownish mud, without odor. About 50 percent sand.	(1) 24 (2) 8 (4) 2	(7) 5 (11) 9	(10) 1 (13) 300 (8) 8 (12) 3
1938				
February.....	Yellowish. 50 percent sand. No odor. Small amount plant detritus.	(1) 2	.....	.....
March.....	Sample is $\frac{1}{2}$ sand, with a little yellow mud, without odor.	No organisms found		
May.....	Brownish. 2 percent sand. No odor. Small amount of detritus.	(1) 36 (2) 1	(14) 1 (7) 1	.....
July.....	Brownish. Is one-third sand. No odor. Small amount detritus.	(1) 14 (4) 2	(14) 2	.....

See footnote at end of table.

Table XLII.—Summary of Scioto River bottom sediments at Lucasville—
Continued

Month	Physical condition	Organisms in 1 liter		
		Pollutional (worms)	Tolerant (chironomid larvae, etc.)	Cleaner (gill-breathers)
1938				
August	Brownish, soft. No odor. One-fifth of sample is coarse sand. Large amount chaffy detritus.	(1) 130 (2) 2	(7) 2	(9) 3
September	Yellowish, soft. No odor. One-sixth sand and pebbles. Small amount plant detritus.	(1) 90 (15)	(7) 10	(16) 2
October	Brownish, granular. No odor.	(1) 64	(7) 29	(16) 1
November	Brown, soft. No odor. Small amount detritus.	(1) 30	(7) 14	(17) 4
December	Brown, soft. No odor. Leaves, etc. in sample.	(1) 280 (3) 4, (4) 16	(7) 12	(17) 4
1939				
January	Brownish, granular. No odor. Large content of whitish fibers.	(1) 3 (4) 5	(7) 13	(10) 3
April	Grayish, compact. Three-fourths gravel and sand. No odor. Small amount detritus.			(10) 4 (18) 4
May	Yellow, soft. No odor.	(1) 21 (1) (21) 106	(7) (19) 60 (20) 3 (11) 4	
June	Chiefly clean sand and gravel. (70 percent). A little yellow mud. No odor.	No organisms found		

(1) *Limnodrilus*, (2) *Tubificex*, (3) *Multicoronatus*, (4) *Dero*, (5) *Aulophorus*, (6) *Naies*, (7) Chironomid larvae, (8) *Ephemera*, (9) *Ephemera*, (10) *Hydropsyche*, (11) *Ceratopogon*, (12) Caddis larvae, (13) Snails (*Amnicola*) (14) Leech, (15) Many worms abnormal, (16) *Hezania*, (17) *Isoperla*, (18) *Gomphus*, (19) 2 were *C. decorus*, (20) *Psychoda*, (21) Newly hatched.

No samples were collected in December 1937; January, April, June, 1938; or February, March, 1939.

Eight of the seventeen bottom samples taken show a high percent (50 to 95) of sand and gravel. Five samples show less than 50 percent, and the remaining four show traces only. The color, in all cases save one, is yellow or brownish—the exception noted showing a grayish color. As to odor, this was absent in every case. Small amounts of plant detritus were present in about half the samples, one of which contained considerable amounts of paper-mill waste.

Thirteen of the seventeen samples contained tubificid worms. In 3 samples the worms numbered over 100, in five samples they numbered 25 to 90, in five other samples fewer than 25 were present.

The Lucasville environment apparently is not favorable for tubificid worms. In several samples the few worms present were badly broken, with bleached, nearly lifeless posterior of body in a "beaded" condition, showing deep constrictions, as if the worm were in that process of sloughing-off and slow death which has been observed frequently in laboratory cultures. In one sample, only 8 or 9 worms in a catch of 90 were normal. In another catch of 64, most of the worms were in fragments. In still another catch of 20, only 2 worms were normal.

The above refers to adult worms. With regard to young worms, these were observed to be present in larger relative number than was

the case at any other station. In one catch of 14, all were small; in another catch of 127, 83 percent were recently-hatched worms. In still another case, a catch of 130 showed 47 percent young and 35 percent of moderate size only. Some egg-capsules were found, but all were empty.

It seems probable that there is a reasonable explanation for each of the above items * * * (1) The adult worms are few in number, and many are in process of gradual death, because of the persistence of a relatively clean environment, instead of the foul conditions in which these worms are known to thrive. No sample examined showed breeding as indicated by the actual presence of living egg-capsules, and a reasonable explanation of this fact is that environmental conditions were not sufficiently favorable to maintain the adult worm and encourage its normal activities, of which breeding is one. (2) Young worms, however, were relatively numerous, in spite of the apparent absence of living egg-capsules. This in turn is a probable and natural result of the fact that these smooth spheroidal capsules, non-gelatinous and lying unattached in or on the mud surface of upstream stations (where they were frequently found in large numbers) are very easily transported by any moderate water movement such as might be caused by the frequent floods in the Scioto River. Wherever these capsules came to rest in the stream they would eventually hatch—but the resulting young worms, relatively numerous for a time, would in all probability gradually succumb to the unfavorable conditions that seem to be increasingly effective, as the worms in decreasing numbers attain the condition of crippled maturity previously discussed.

Subsequent laboratory studies (to be reported in a forthcoming paper) resulted as follows:

1. Tubificid capsules hatched successfully in (a) distilled water, (b) clean tap water, (c) sewage-polluted water, (d) clean sand, kept moist with clean water.
2. About half of the young worms, each about 8 mm. long, were kept in their native environment, as given in 1. They lived for 2 to 6 weeks, showing very slight growth meantime.
3. The remaining young worms hatched in 1 (above) were transferred to sewage-polluted mud. In 6 weeks they had attained a length of about 2 inches.

Consistent with the decreasing numbers of these pollutional worms is an increase in the frequency and the relative numbers (1) of such organisms as are tolerant of pollution, and also (2) such organisms as are normally abundant in the cleaner, fish-containing waters, notably the water-dwelling stages of insect life such as May flies, caddis flies, stone flies, and the like.

DISCUSSION

The following tabulation (table XLIII) shows the essential situation in this respect at all the stations studied.

Table XLIII.—*Number of samples showing index organisms August 1937 to June 1939*

Miles	Station	Samples taken	Samples whose population is classified as					
			Pollutional		Tolerant		Cleaner	
			Number	Percent	Number	Percent	Number	Percent
3	Columbus.....	21	21	100	0	0	0	0
13	Shadeville.....	21	21	100	4	19	0	0
17	Commercial Point.....	18	18	100	6	33	0	0
23	South Bloomfield.....	22	22	100	8	36	2	9
46	Kellenburg.....	20	20	100	16	80	3	15
61	Chillicothe.....	19	18	95	15	79	3	16
115	Lucasville.....	17	13	76	12	71	9	53

It will be observed that, in the upper polluted portion of the river (the first three stations) the "cleaner" organisms are entirely absent. They appear in very small numbers (in 9 percent of the samples—see final column) at South Bloomfield, and in the lower, well-recovered river this frequency is much increased—these better organisms being found in 15 percent, 16 percent, and finally 53 percent of the samples, respectively, at the lower river collecting stations. Meantime, the increase in frequency of occurrence of the "tolerant" organisms follows a somewhat similar course, averaging about 17 percent of the samples, in the upper polluted river as compared with an average of 73 percent in the samples of the lowermost three stations. The pollutional samples, however, show a different course. They are *decreasing* downstream—from 100 percent in the upstream stations to about 92 percent in the lowermost three stations or 76 percent at the lowermost one.

Table XLIII is an example of tabulated data of the type that must be interpreted with care, and with adequate knowledge of the facts involved, and further, with due consideration of the limitations of a "table" such as the one referred to.

Table XLIII is considering data in the qualitative sense only. In other words, the column marked "pollutional" records (Fact I) the mere presence—not the actual numbers) of pollutional organisms in 100 percent of all the samples taken, for instance, at Shadeville, and in 76 percent of all the samples taken at Lucasville. This does not necessarily mean that the pollutional condition at Lucasville is about 76 percent that of Shadeville. The need for adequate knowledge of the facts now becomes imperative, for when we note (Fact II) that the average content of these pollutional organisms (see table

XXXVII) at Shadeville is about 10,000, while at Lucasville the average is only 58, the real difference in sanitary status at the two stations becomes apparent.

The same general situation is seen in the column headed "cleaner." It so happens (Fact III) that none at all of the Shadeville samples showed the presence of any of the cleaner organisms, notably insect larvae, but that these were present in 53 per cent of the Lucasville samples. But again further knowledge of the facts in the situation now reveals (Fact IV) that the average content of "cleaner" organisms in Lucasville samples is only 3 (see table XXXIV). Although this is infinitely greater than the zero value at Shadeville, yet we instinctively compare this apparently low average of 3 cleaner organisms at Lucasville with the previously-mentioned average content of 58 pollutional organisms in these same samples. The unguarded conclusion is that Lucasville samples show continued pollution, rather than recovery from this condition so prevalent in the Shadeville section. But again a further fact of far greater importance than are mere numbers of organisms, claims consideration—that is (Fact V) the higher form of life represented by these insect larvae (though few in number) and the greatly improved conditions of environment that must be operative in order to make possible the continued presence of even *one* such organism. In fact, this is an item that condemns the Shadeville samples: conditions there are so intolerable that, in 21 samples, representing every season, not even one of these cleaner organisms was found.

The information sought is this: What is the relative sanitary status of the stream as indicated by conditions existing in the bottom sediments? At Shadeville, for instance (1) the physically vile, stinking sediments always present give unanimous assent, so to speak, that sanitary conditions are bad: (2) The persistent presence, in large numbers, of such organisms as are known to flourish only in a highly organic environment, is further evidence, biological rather than physical, of the prevalence of pollution. By the same token, (3) the total absence for nearly two years of any organism of known preference for clean environment constitutes further condemnatory testimony. At Lucasville, on the contrary, (1) sediments are odorless and apparently clean. (2) The pollutional organisms, though actually present in 77 per cent of the samples, are very greatly decreased in numbers—about *one-half of 1 percent* of the high numbers always present in Shadeville samples. Clearly, some change has occurred that makes the Lucasville environment a very unfavorable one for these pollutional forms. (3) Positive evidence relative to this last statement is furnished by the presence, in small numbers, but in 53 percent of the samples, of such clean-water forms as could not survive at all under conditions of pollution, and as a matter of fact were not

found at all in any of the polluted samples taken at Shadeville. This is unmistakable evidence of the prevalence and persistence of such better conditions as make possible the presence of these higher forms of life—gill-breathing and oxygen-using insect larvae usually abundant in fish-inhabited waters.

No correlation of worm count with hydrographic conditions.—The hydrograph presented herewith (figure 38) was compiled from discharge calculations based on the daily gage height readings taken at Chillicothe, about midway of the length of the Scioto River. The time included is August 1937 to June 1939, inclusive, this being the period covered by the bottom samples collected. The computed mean discharges only are plotted.

The hydrographic conditions shown on the graph may be arranged in three classes, namely: I. Stable; II. Moderately stable; and III. Disturbed. For convenience, the Roman numerals designating these classes are entered upon the graph in each month, at the bottom.

Reinspection of the 16 complete worm counts at stations Columbus, Shadeville, and Commercial Point (see table XXXIII) reveals the following:

In four counts (April, September, and December 1938 and May 1939) the worm content at the three stations does not fluctuate unreasonably. The lowest count in any instance is 30 percent or more of the highest count. There are no extreme variations, for instance, in 5,300, 14,100, and 5,900; or in 8,000, 6,700 and 6,100. The four counts mentioned above may be regarded as reasonable.

The remaining 12 counts show the extreme fluctuations that have already been discussed in preceding pages, as due chiefly to the occurrence of the worm in groups, in the bottom sediment. The lowest count is always less than 25 percent of the highest (less than 15 percent in all but one case). Inspecting the possible relation of these 12 with the hydrographic conditions given in the graph, we find:

Seven of the erratic counts occurred when hydrographic conditions were stable. (See counts of August and November 1937, and June, July, October, and November 1938, and January 1939. Note condition of hydrograph at these times).

Two occurred when hydrographic conditions were moderately disturbed. (See counts of May and August 1938).

Three of the erratic counts occurred at times of disturbed, or greatly disturbed hydrograph. (See counts also hydrograph, of December 1937, and April and June 1939).

It thus appears that of these 12 erratic counts a majority of them occurred when hydrographic conditions were stable. It is, therefore, indicated that disturbed hydrographic conditions and floods are a minor factor, if any, in producing the widely fluctuating counts recorded in table XXXIII. It is further indicated that such flood con-

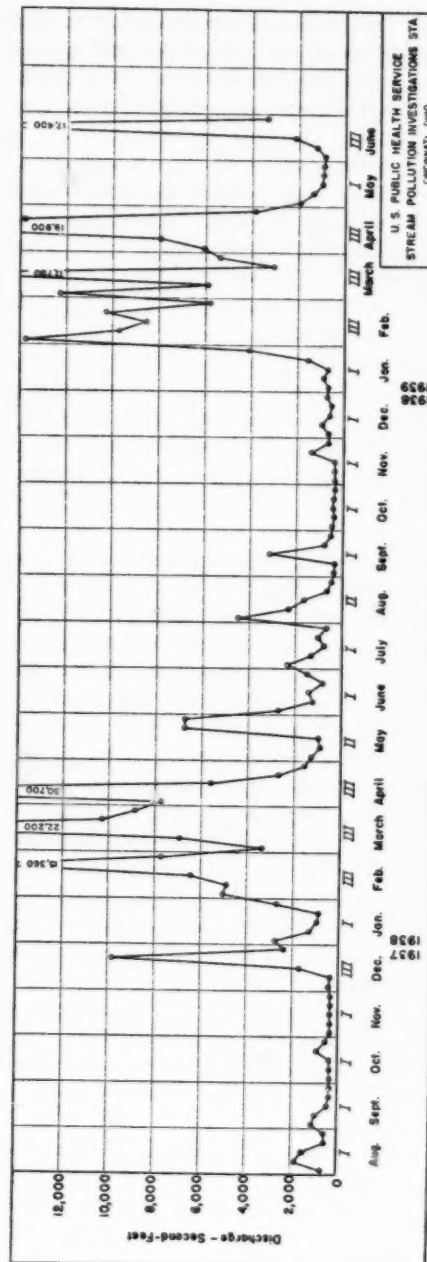


FIGURE 36. AVERAGE WEEKLY DISCHARGE IN C. F. S. AT CHILICOTHE THROUGHOUT THE SURVEY.

ditions as are encountered in the Scioto River do not materially affect the resident population of sludge worms. They are not swept out by even such extreme high water as that of March and April 1938, and February, March, and April 1939. This is probably due largely to the extreme susceptibility of this worm to any disturbance. The disturbed worm instantly withdraws into the mud—and unless this is removed in relatively large amounts, the chances are that most of the worms, burrowing deeper, remain in that location until hydrographic disturbance has subsided.

Tubificid worms as indicators of sewage pollution.—In 1913 Forbes and Richardson (37) studied the Illinois River, grossly polluted by the flood of Chicago sewage. Their report emphasizes the "immense numbers of sludge worms" found in the foul sludges where practically no other form of animal life existed. The dissolved oxygen content of the water ranged from 3.1 to 16.4 percent of saturation.

In this same year the author of this paper studying the Potomac River found large numbers of tubificid worms just below the Washington sewer outfall. In sediment samples downstream from this point the worms decreased rapidly.

Later study of the Ohio River (49) told essentially the same story. Heavy sewage pollution at Pittsburgh resulted in about 3,000 worms per liter of sediment, but 460 miles downstream there was less than 1 worm per liter until Cincinnati sewage raised this average to 450 worms per liter. Four hundred and fifty-eight miles below Cincinnati the worms were not found at all.

In further studies on the sewage-polluted Illinois River, Richardson (39) records that when pollution increased, certain cleaner animal forms decreased from 1,709 to 46, but the sludge worms meantime *increased* from 16 to 2,463.

In our study of the Illinois River (44), 267 miles of the stream were included, and all seasons of the year were represented by the monthly bottom samples (over 200) examined. We found, (1) moderately large numbers (over 2,000) of worms per liter of sediment in the polluted section of the river at Chillicothe, Illinois, and above, (2) steadily decreasing numbers, an average of 48 per liter, downstream (Havana) as the water gradually recovered. (3) Still further decrease in the lower sections of river, average of 13 per liter, where the sediments had a clean earthy odor and also showed numerous cleaner organisms such as insect larvae commonly found in streams which contain fish.

In 1917 Weston and Turner (46) record finding in the sewage-polluted Coweset stream, large numbers of tubificidae below the point of pollution, and refer to the worm as "a typical pollution organism."

Richardson (39) justly raises the question why tubificid worms should be practically absent in the lower end of the Sanitary Canal which is grossly polluted with Chicago sewage, and is also septic at times, and infers that if the worms are to be relied on as indicator organisms, they should be present in such an environment.

In connection with this matter, we offer the following results of our own study (44) in 1921-22:

1. Bottom samples are very difficult to obtain, in the lower portion of this canal, on account of the bottom covering of riprap. In six visits, we secured very small samples, and only four times. One sample was later lost by breakage.

Of the three small samples left, one only contained any worms, and these were few in number. No other living organism was found except *Leptomitris*, a sewage fungus, and *Curchesium*, a stalked ciliate protozoan commonly found in sewage-polluted water.

3. Our own samples were so few, and so small in quantity, that we attach little importance to the apparent lack, relatively speaking, of tubificid worms. In view of the habit of the worms to occur in patches or groups, it would be possible to miss them entirely in so few samples. Furthermore, an actual experience in our Scioto study may be a partial explanation, as follows: A small area of stream bottom at the polluted Shadeville section was covered with fist-size pebbles. On these pebbles there was practically no sediment, but *between* them, in the interstices, were accumulations of sediment, and large numbers of tubificid worms, but these worms were obtained only by obtaining *the pebbles and the attendant sediment* wedged between. Such samples were impossible to obtain in the lower section of the Sanitary Canal because of the large size of the riprap.

In 1928, Cutler (31) studying the polluted Buffalo Creek, comments on the bottom conditions of that creek "covered with foul-smelling sludge and furnishing ideal surroundings for the growth of such foul-water organisms as tubifex * * *."

In 1930, Farrell (45) studying the Salmon River, states that the original fauna grow less and less as the pollution increases until finally, in the area of greatest pollution * * * the normal forms have completely disappeared and the sludge worm *Tubifex tubifex*, biological indicator of rank pollution, alone is found.

In 1932, Ludwig (43) found insect larvae dominant in the unpolluted upper Hocking River, but extremely foul conditions, together with immense numbers of sludge worms, below the point where the city sewage entered the stream.

The wise words of Cutler (31) furnish a fitting close for this brief summary relative to sludge worms and sewage pollution. He says,

"Thus the sludge worm *Tubifex tubifex* is present often in clean water but it *abounds* under conditions of severe pollution. It is the relative abundance of certain foul-water organisms and the scarcity of fresh-water-loving forms that indicate the degree of pollution."

SUMMARY OF BOTTOM SEDIMENT STUDIES

1. Bottom sediments, formerly the suspended matter (in part) of the water constitute an accumulation of evidence as to the average sanitary status of the water that has passed downstream. Sewage-polluted streams deposit organic solids, forming sludge banks. Putrescible sediments do not result from clean suspended matter such as silt.
2. Organisms thrive or succumb in proportion to the suitability of the environment, or lack of such suitability. Putrescible bottom sediments, with low oxygen content, can be tolerated by but few animal forms, such as are provided with a breathing tube (rat-tail maggot) or are adapted physiologically to cope successfully with low oxygen concentration, as are tubificid worms.
3. Studies of various stream bottoms have shown that sediments in heavily polluted streams contain a large predominance of tubificid worms, and few or none of such forms (chiefly insect larvae) as are common in streams known to be unpolluted. These latter streams, meantime, contain only a very few of the tubificid worms. Moreover, if the stream becomes more polluted, the tubificid worms in the sediment increase rapidly, and the cleaner forms decrease. Thus these organisms that thrive in the bottom sediments constitute a useful index of the sanitary status of the stream bottom.
4. Because bottom sediments are thus valuable in the sanitary study of a stream, these sediments must be collected with adequate care, in sufficient number, and quantity, and with due regard to the known habits of distribution, under natural conditions, of such organisms as may be present. Because tubificid worms usually occur in patches or colonies, certain precautions are imperative in collecting the bottom sample, or these colonies may be missed entirely.
5. The Scioto River, polluted by sewage effluent, is here studied, in accordance with the principles and methods already given. It is shown that bottom sediments indicate by physical condition and organism content, essentially the real sanitary condition of the stream, and that prevalence of tubificid worms, in samples collected with proper care, is an indication of heavy organic pollution. The worms decrease rapidly as the water improves, are not washed out by seasonal floods, and are stable and reliable generally.

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APPENDIX I

Nitrogen determinations have been made on composite monthly samples from five selected sampling points: Columbus, Shadeville, Red Bridge, Chillicothe, and Lucasville. The use of these determinations as parameters of pollution is doubtless well understood. Briefly, there should be no loss of nitrogen regardless of changes in its state of combination, except as gaseous nitrogen or compounds, by incorporation into living organisms or by sedimentation. Loss of nitrogen in a gaseous state is probably negligible and the others may be regarded as only temporary losses. The total nitrogen found at any given point must necessarily be the sum of all the nitrogen added to the stream above that point minus, of course, whatever losses may have occurred as previously stated. This holds true for units of quantity.

Concentrations which are the values determined, are affected by additional inflow of water containing higher or lower concentrations of nitrogen. Quantity units are obtained by multiplying the concentrations (parts per million) by the volume (second-feet). These units may be converted by using the following factors if the volume used is expressed in second-feet times one thousand:

Quantity units=28.317 grams per second,
=2,446,589 grams per day,
=5,393.69 pounds per day.

In addition to this permanence of nitrogen, a progressive and orderly change from complex organic compounds to ammonia, nitrite, and finally nitrate should be exhibited as the distance from the source of pollution increases.

The data obtained are presented in tables 1 to 5 in p. p. m. and as quantity units. As the sewage of the city of Columbus was the largest single source of pollution, the type of treatment used at the Columbus Sewage Treatment Plant is also indicated. All data collected are included in these tables regardless of discharge rate. However, the quantity of nitrogen present at any time is intimately associated with discharges and incidentally with the season as higher discharge rates normally prevail at definite times of the year. Reference to the tables will emphasize this point. An increase in stream flow and similar increase in total nitrogen can be expected in February, March, and April, again in June and frequently in July. The higher the discharge rate the more total nitrogen to be found in the stream. It is quite evident that this regular rise in nitrogen with increase in

stream flow has to be attributed to nitrogen supplied by surface drainage. With this increase in discharge rate and total nitrogen, there is a corresponding increase in suspended solids. Similar changes were noticed on the Ohio River where the correlation between discharge rates, turbidities, and total nitrogen was shown.* In a comparatively small stream, such as the Scioto, these changes in discharge are often sudden and extensive. As it is difficult to distinguish between nitrogen added from known pollution or tributary sources and nitrogen due to surface drainage the interpretation of nitrogen figures presents obstacles. Apparently nitrogen attributable to surface drainage often exceeds that from other sources.

Table 1.—Nitrogen determinations on monthly composites—Columbus

Month	Dis-charge thou- sands of c. f. s.	Constituents in p. p. m.				Quantity units p. p. m. X thousand second-feet			
		Free am- monia	Nitro- gen oxides	Organ- ic ni- trogen	Total nitro- gen	Free am- monia	Nitro- gen oxides	Organ- ic ni- trogen	Total nitro- gen
TRICKLING FILTERS									
1937									
February	1.758	0.14	0.12	0.24	0.50	0.246	0.211	0.122	0.579
March	1.043	.34	.02	.20	.56	.355	.021	.200	.576
April	2.097	.35	.04	2.60	2.99	.734	.084	5.452	6.370
May	.676	.40	.07	.20	.67	.270	.047	.135	.453
June	3.493	.19	.09	.20	.47	.663	.279	.699	1.641
July	1.933	.32	.04	.40	.76	.619	.077	.773	1.469
August	.391	.37	.01	1.10	1.48	.145	.004	.430	.579
September	.144	.56	.03	.96	1.55	.081	.004	.139	.223
October	.254	.80	.46	1.32	2.58	.203	.117	.335	.655
November	.107	.32	.67	.17	1.06	.034	.061	.018	.113
PLAIN SEDIMENTATION									
December	1.152	0.48	0.90	0.92	2.30	0.553	1.037	1.060	2.650
1938									
January	.588	.30	1.44	.70	2.44	.170	.847	.412	1.425
February	2.650	.22	1.20	.78	2.40	.583	3.180	2.067	6.360
March	4.427	.70	1.92	.46	3.08	3.090	8.500	2.036	13.635
April	4.387	.30	2.01	.26	2.57	1.316	8.818	1.141	11.276
May	.771	.26	1.50	.24	2.00	.200	1.157	.185	1.542
July	.191	.32	2.40	.38	3.10	.061	.458	.073	.592
ACTIVATED SLUDGE									
August	0.660	0.39	0.66	0.74	1.79	0.257	0.436	0.488	1.181
September	.220	.43	.25	.82	1.51	.095	.095	.180	.372
October	.105	.66	.09	.60	1.35	.069	.069	.063	.192
November	.145	2.03	.02	.77	2.82	.204	.003	.112	.408
December	.233	.40	.71	.90	2.01	.063	.165	.210	.468
1939									
January	.646	.38	1.32	.74	2.44	.245	.853	.478	1.576
February	3.065	.29	1.68	1.10	3.07	.846	5.132	3.361	9.379
March	5.088	.44	1.51	.95	2.90	2.239	7.683	4.834	14.755
April	3.484	.34	.72	1.13	2.19	1.185	2.508	3.937	10.104
May	.392	.23	.80	.89	1.91	.030	.314	.349	.749
June	2.680	.65	1.80	.67	3.15	1.742	4.824	1.796	8.174
July	.931	.30	.75	.70	1.80	.279	.698	.651	1.676

*U. S. Public Health Service. Public Health Bulletin No. 143—A Study of the Natural Purification of the Ohio River, p. 190.

Table 2.—Nitrogen determinations on monthly composites—Shaderville

Month	Dis-charge thou- sands of c. f. s.	Constituents in p. p. m.				Quantity units p. p. m. X thousand second-feet			
		Free am- monia	Nitro- gen oxides	Orga- nic ni- trogen	Total nitro- gen	Free am- monia	Nitro- gen oxides	Orga- nic ni- trogen	Total ni- trogen
TRICKLING FILTERS									
1937									
February	1.846	1.00	0.12	0.48	1.60	1.840	0.221	0.883	2.944
March	1.093	.70	.05	.80	1.55	.765	.065	.874	1.694
April	2.195	1.40	.03	2.80	4.23	3.673	.066	8.146	9.285
May	.707	1.25	.06	.28	1.59	.884	.042	.198	1.124
June	3.658	1.00	.63	.72	2.35	5.853	.110	2.634	8.596
July	2.123	1.16	.64	.80	2.60	2.347	.080	1.618	4.045
August	.409	3.50	.01	2.40	5.91	1.432	.004	.982	2.417
September	.151	5.60	.01	3.60	9.21	.846	.002	.544	1.391
October	.296	3.00	.48	5.00	8.06	.958	.122	1.330	2.410
November	.112	3.80	.15	.38	4.23	.436	.017	.081	.474
PLAIN SEDIMENTATION									
December	1.207	5.20	0.34	1.47	7.01	6.276	0.410	1.774	8.460
1938									
January	.615	3.00	1.13	1.20	5.33	1.845	.695	.738	3.278
February	2.773	.78	1.36	.42	2.56	2.162	3.771	1.163	7.096
March	4.624	.90	2.13	1.10	4.13	4.162	9.849	3.086	19.097
April	4.586	1.15	1.45	.75	3.35	5.274	6.650	3.440	15.363
May	.809	3.84	.65	1.96	6.45	3.107	.826	1.886	5.218
July	.199	6.20	.75	.80	7.75	1.234	.149	.159	1.542
ACTIVATED SLUDGE									
August	0.691	1.23	0.70	0.70	2.63	0.650	0.484	0.484	1.617
September	.231	3.25	.90	1.63	5.18	.751	.208	.238	1.197
October	.110	5.50	.27	1.20	6.97	.605	.680	.132	.767
November	.152	4.30	.11	.80	5.21	.654	.017	.122	.792
December	.243	5.40	.08	2.10	7.58	1.312	.019	.510	1.842
1939									
January	.677	4.30	.70	2.45	7.45	2.911	.474	1.659	5.044
February	3.194	.86	1.18	1.94	3.68	1.789	3.709	6.196	11.754
March	5.326	.90	1.69	1.30	3.89	4.793	9.000	6.924	20.718
April	3.646	.48	1.04	1.32	2.84	1.759	3.792	4.813	10.355
May	.410	1.34	.30	1.51	3.15	.540	.123	.610	1.292
June	2.804	2.25	1.40	.95	3.60	8.389	3.926	2.664	10.004
July	.974	.70	1.20	.90	2.80	.682	1.109	.877	3.727

Table 3.—Nitrogen determinations on monthly composites—Red Bridge

Month	Dis-charge thou- sands of c. f. s.	Constituents in p. p. m.				Quantity units p. p. m. X thousand second-feet			
		Free am- monia	Nitro- gen oxides	Organ- ic ni- trogen	Total nitro- gen	Free am- monia	Nitro- gen oxides	Organ- ic ni- trogen	Total nitro- gen
TRICKLING FILTERS									
1937									
February	3.136	0.32	0.08	0.64	1.04	1.004	0.251	2.007	3.261
March	1.658	.60	.03	.60	1.23	.995	.050	.995	2.039
April	3.123	.70	.02	1.40	2.12	2.186	.062	4.372	6.621
May	1.502	.75	.05	.32	1.12	1.127	.075	.481	1.682
June	4.486	.78	.02	.18	.98	3.499	.089	.807	4.396
July	3.222	.50	.03	.64	1.17	1.611	.097	2.062	3.770
August	.638	1.12	.02	1.50	2.64	.715	.013	.957	1.684
September	.346	1.65	.06	2.00	3.71	.571	.021	.692	1.284
October	.376	2.20	.90	4.12	7.22	.827	.338	1.549	2.715
November	.225	2.00	.18	1.12	3.30	.450	.041	.252	.743

Table 3.—Nitrogen determinations on monthly composites—Red Bridge—Continued

Month	Discharge thous- ands of c. f. s.	Constituents in p. p. m.				Quantity units p. p. m. X thousand second-feet			
		Free am- monia	Nitro- gen oxides	Organ- ic ni- trogen	Total nitro- gen	Free am- monia	Nitro- gen oxides	Organ- ic ni- trogen	Total nitro- gen
PLAIN SEDIMENTATION									
December.....	1.828	3.00	0.70	1.00	4.70	5.484	1.280	1.828	.859
1938									
January.....	1.117	1.30	1.00	0.90	3.40	1.676	1.117	1.008	3.798
February.....	4.496	.50	1.44	.40	2.34	2.248	6.474	1.798	10.521
March.....	9.213								
April.....	4.513								
May.....	1.919	1.20	1.00	3.40	5.60	2.303	1.919	6.525	10.746
July.....	.488	1.70	1.40	.30	3.40	.830	.083	.146	1.659
ACTIVATED SLUDGE									
August.....	1.197	0.71	0.60	0.82	2.13	0.850	0.718	0.982	2.550
September.....	.634	.48	.48	1.30	2.16	.304	.394	.761	1.369
October.....	.237	1.98	.13	.62	2.73	.469	.031	.147	.647
November.....	.342	.74	.28	.70	1.72	.253	.066	.239	.588
December.....	.457	2.25	.45	1.35	4.25	1.028	.297	.617	1.942
1939									
January.....	.957	2.10	.65	1.00	3.75	2.010	.622	.957	3.589
February.....	5.534	.50	.75	2.50	3.75	2.767	4.151	13.835	20.753
March.....	6.962	.52	1.42	1.48	3.42	3.464	9.460	9.860	22.784
April.....	6.583	.54	1.84	1.70	4.08	3.555	12.113	11.191	26.859
May.....	.816	.25	.87	1.36	2.49	.294	.196	.710	1.110
June.....	3.744	.85	1.60	1.07	3.52	3.182	5.990	4.006	13.179
July.....	1.492	.43	1.40	.77	2.60	.642	2.069	1.140	3.879

Table 4.—Nitrogen determinations on monthly composites—Chillicothe

Month	Discharge thousands of c. f. s.	Constituents in p. p. m.				Quantity units p. p. m. X thousand second-feet			
		Free ammonia	Nitrogen oxides	Organic nitrogen	Total nitrogen	Free ammonia	Nitrogen oxides	Organic nitrogen	Total nitrogen
BUCKLING FILTERS									
1937									
February.....	4.849	0.30	.099	0.86	1.15	0.970	0.044	4.170	5.576
March.....	2.476	.40	.04	.40	.84	.990	.099	.990	2.080
April.....	4.481	.44	.03	2.40	2.87	1.972	.134	10.754	12.860
May.....	2.160	.25	.06	.20	.51	.540	.130	.432	1.102
June.....	7.242	.22	.08	.28	.58	1.602	.383	2.040	4.224
July.....	4.295	.40	.05	.48	.93	1.718	.215	2.062	3.994
August.....	1.319	.48	.03	1.30	1.71	.633	.040	1.583	2.255
September.....	.485	.36	.14	1.14	1.64	.175	.068	.553	.795
October.....	.515	.76	1.30	1.00	2.96	.391	.618	.515	1.524
November.....	3.68	.76	.28	.64	1.68	.280	.103	.226	.618
PLAIN SEDIMENTATION									
December.....	2.918	1.92	1.40	0.78	4.10	5.603	4.085	2.276	11.964
1938									
January.....	1.528	0.70	1.20	.80	2.70	1.070	1.834	1.222	4.126
February.....	7.378	.32	1.12	.88	2.32	2.361	8.393	6.493	17.117
March.....	11.884	.76	1.50	.54	2.80	0.032	17.325	6.417	33.275
April.....	4.762	.36	1.60	.10	2.06	1.714	7.619	.476	9.810
May.....	3.829	.56	1.20	.04	1.80	2.144	4.595	.153	6.892
July.....	.816	.42	1.60	.38	2.60	.343	1.460	.310	2.122

Table 4.—Nitrogen determinations on monthly composites—Chillicothe—Continued

Month	Dis-charge thous- ands of c. f. s.	Constituents in p. p. m.				Quantity units p. p. m. × thousand second-feet			
		Free am- monia	Nitro- gen oxides	Organ- ic ni- trogen	Total nitro- gen	Free am- monia	Nitro- gen oxides	Organ- ic ni- trogen	Total nitro- gen
ACTIVATED SLUDGE									
August	2.452	0.45	0.80	1.07	2.32	1.103	1.962	2.624	5.689
September	1.007	.37	.20	.90	1.47	.406	.210	.987	1.613
October	.391								
November	.547	.40	.18	.50	1.08	.219	.098	.274	.591
December	.697	1.24	.70	1.04	2.98	.864	.498	.725	2.077
1939									
January	2.770	1.00	1.22	1.16	3.38	2.770	3.379	3.213	9.363
February	12.920	.30	.84	2.40	3.54	3.876	10.853	31.008	45.737
March	9.544	.56	1.13	1.60	3.29	5.345	10.785	15.270	31.400
April	10.174	.32	.64	.98	1.94	3.256	6.511	9.971	19.738
May	1.431	.31	.36	.59	1.36	.444	.515	.844	1.846
June	6.163	.14	1.20	1.26	1.60	.863	7.396	7.765	9.861
July	2.237	.37	.64	.80	1.81	.828	1.432	1.700	4.050

Table 5.—Nitrogen determination on monthly composites—Lucasville

Month	Dis-charge thous- ands of c. f. s.	Constituents in p. p. m.				Quantity units p. p. m. X thousand second-feet			
		Free am- monia	Nitro- gen oxides	Organ- ic ni- trogen	Total nitro- gen	Free am- monia	Nitro- gen oxides	Organ- ic ni- trogen	Total nitro- gen
TRICKLING FILTERS									
1937									
February	8.687	0.40	0.21	0.77	1.38	3.474	1.824	6.689	11.988
March	4.134	0.14	0.07	0.20	0.41	.579	.280	.827	1.695
April	6.731	1.20	0.01	2.00	3.21	8.077	.067	13.462	21.607
May	3.772	0.15	0.03	0.12	0.30	.596	.113	.453	1.132
June	11.728	0.14	0.07	0.32	0.53	1.642	.821	.375	6.216
July	5.840	0.36	0.07	0.24	0.67	2.102	.409	1.402	3.913
August	2.490	0.48	0.03	1.10	1.61	1.195	.747	2.739	4.099
September	1.120	0.40	0.28	1.10	1.78	.448	.314	1.282	1.994
October	.989	0.28	0.70	0.67	1.65	.278	.092	.863	1.632
November	.614	0.26	0.35	0.14	0.75	.160	.215	.086	.461
PLAIN SEDIMENTATION									
December	4.508	0.74	0.68	0.61	2.03	3.403	3.127	2.805	9.334
1938									
January	2.818	0.42	0.06	0.78	2.16	1.184	2.705	2.198	6.087
February	11.215	0.20	1.44	1.00	2.64	2.243	16.150	11.215	29.608
March	20.858	0.44	1.60	0.25	2.29	9.178	33.373	5.215	47.765
April	8.102	0.24	1.29	0.29	1.82	1.944	10.452	2.350	14.746
May	9.145	0.42	0.75	1.98	3.15	3.941	6.850	18.107	28.907
July	2.105	0.12	1.60	0.41	2.13	.253	3.368	.863	4.484
ACTIVATED SLUDGE									
August	4.865	0.34	0.70	1.07	2.11	1.654	3.406	5.206	10.265
September	1.721	0.37	0.24	0.76	1.37	.585	.413	1.308	2.338
October	.624	0.68	0.12	0.62	1.42	.424	.075	.387	.886
November									
December	1.190	0.68	0.82	0.97	2.47	.815	.983	1.153	2.962
1939									
January	5.037	0.68	0.21	1.08	1.97	3.425	1.058	5.440	9.923
February	23.343	0.23	1.11	2.50	3.93	5.369	25.911	60.458	91.738
March	14.244	0.50	0.96	2.38	3.84	7.122	13.674	33.801	54.697
April	12.043	0.34	0.64	0.90	1.88	4.095	7.706	10.830	22.641
May	2.858	0.14	0.22	0.70	1.06	.400	.629	2.000	3.029
June	8.390	0.15	1.33	1.09	2.50	1.259	11.150	9.145	20.975
July	3.092	0.30	0.80	0.70	1.80	.927	2.474	2.164	5.566

Mean results expressed in quantity units for each period of plant operation; trickling filter, plain sedimentation and activated sludge are presented in table 6. In this table all results which appear to be unduly affected by high discharge rates are omitted.

Table 6.—Mean quantity units of nitrogen present for each period of Columbus sewage treatment plant operation

Sampling point	Discharge thousand second- feet	Quantity units			
		Free ammonia	Nitrogen oxides	Organic nitrogen	Total nitrogen
TRICKLING FILTER OPERATION					
Columbus.....	0.788	0.244	0.008	0.308	0.620
Shadeville.....	0.825	0.623	0.068	0.808	1.496
Red Bridge.....	0.791	0.781	0.090	0.821	1.692
Chillicothe.....	1.221	0.502	0.325	0.718	1.545
Lucasville.....	2.708	0.761	0.397	1.057	2.215
PLAIN SEDIMENTATION					
Columbus.....	0.676	0.248	0.875	0.433	1.556
Shadeville.....	0.708	3.116	0.445	1.064	4.625
Red Bridge.....	1.338	2.573	1.248	2.376	6.197
Chillicothe.....	2.273	2.250	2.990	0.990	6.276
Lucasville.....	4.406	1.606	4.193	2.034	8.663
ACTIVATED SLUDGE OPERATION					
Columbus.....	0.417	0.178	0.317	0.316	0.811
Shadeville.....	0.436	1.038	0.316	0.590	1.934
Red Bridge.....	0.767	0.720	0.544	0.695	1.959
Chillicothe.....	1.604	0.948	1.156	0.270	2.374
Lucasville.....	2.770	1.176	1.291	2.524	4.991

The total nitrogen increases at Shadeville which is below the Columbus sewage treatment plant. This increase is greater during the period of plain sedimentation. The periods of trickling filter and activated sludge operation are quite similar with a tendency for smaller amounts of organic nitrogen to be present during the activated sludge period. There is a definite trend to an increased percentage of nitrogen oxides with increased distance from the source of pollution as can be seen in Table 7.

Table 7.—Percent nitrogen oxides

Station	1st period	2d period	3d period
Columbus.....	10.96	56.23	39.08
Shadeville.....	4.54	9.62	16.34
Red Bridge.....	5.32	20.14	27.77
Chillicothe.....	21.04	47.73	48.69
Lucasville.....	17.92	56.71	25.86

The value of a very extensive program of nitrogen determinations is questionable when the time and expense consumed in accumulating the data is considered and they may be very well omitted entirely

without impairing the survey. Nitrogen determinations are more difficult to acquire and to interpret and are less sensitive than biochemical or bacterial indices of pollution. This is not to be construed as meaning that the determinations are valueless, as individual ones may be very informative. However, it would seem that the only comprehensive program undertaken should be one bracketing points of greatest pollution to be used as a check on the biochemical data and this to be done only at low river stages. Nitrogen data would also be helpful when it was desired to correlate new data with older surveys based on nitrogen indices.

